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THE LIGHT OF THE NIGHT SKY:

Astronomical, Interplanetary and Geophysical.

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[redacted] - TECHNICAL REPORT

1. INTRODUCTION

At night, terrestrial man is bathed in a gentle flow of visual radiation or light. This flux is due, in large part, to his unique and privileged location in the universe. The appearance of the "sky" to a randomly located <u>intergalactic</u> observer with "human" eyes would be in dramatic contrast: no individual stars would be visible, only the integrated light from the many but very distant galaxies. A few of the galaxies would be separately visible, as is the Andromeda nebula to our eyes.

An interstellar observer in a galaxy such as our own has a different view. In the vicinity of the sun he sees the Milky Way much as we see it from the Earth, but without the competition of solar system and terrestrial light that plagues the earth-bound astronomer. His sky is more than a hundred times as bright as the intergalactic observer's.

A move into the solar system but away from the luminosity originating in a planetary atmosphere introduces a new source of light. If, for example, he stands on the moon and looks at the

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* Contribution number .
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sky in general, only about one-third of the light is integrated starlight and about two-thirds the so-called zodiacal light. The visual contrast between the Milky Way and the general sky background is greater than on the earth's surface but less than for the interstellar observer. If he is able to occult the sun and look in a direction of 5° elongation along the ecliptic, the brightness of the zodiacal light is some 200 times the brightest part of the Milky Way and therefore overwhelms it. The zodiacal light in the ecliptic is brighter than the brightest part of the Milky Way until an elongation of about 50°.

Our observer now moves to his terrestrial platform where he can live and breathe and look at the sky in comfort, augmenting his visual observations with instruments which can be firmly established on a solid base that conveniently rotates and revolves in times short compared to a life span. But a price must be paid for these emoluments: an additional primary source of radiation, the night airglow or nightglow, is introduced from the upper atmosphere, and the lower atmosphere interferes with his measurements by scattering and attenuating all primary radiations. Two consolations may be offered. In the first place, the difficulties placed in his way make the whole enterprise of understanding his universe a sporting venture that should inspire him to heroic efforts. And second, it may be said that conditions for observing the universe from the Earth might have been much worse except for the circumstance that the overwhelmingly largest night airglow component (the OH, hydroxyl, radiation) is in the near infra-red just beyond the sensitivity of the human eye. Were this radiation concentrated in the visible part of the spectrum, the Milky Way would be lost in the airglow glare.

We have assembled the general information discussed in these introductory remarks into Table 1 to illustrate the numbers involved and, further, to present in outline form the contents of this review paper. It is proposed to proceed from left to right or from top to bottom in the table which may be taken as from the fundamental to the superficial, from a random position to a privileged one.

It may be noted that the advantage to be gained by escaping from the earth's surface into interplanetary space via an artificial satellite is real but not large within the context of this discussion (compare columns 4 and 5 in Table 1). Necessarily all studies of general sky brightness will, for the interplanetary astronaut, involve both zodiacal light and integrated starlight to the disadvantage of the latter. The particular advantage of a satellite program is in the exploration of those wave-length regions to which the human eye is insensitive and the terrestrial atmosphere impervious.

II. COMMENTS ON THE VISUAL SPECTRAL REGION.

A general treatment might well include both particulate and electromagnetic fluxes. Even a limitation to electromagnetic radiation should include such extreme manifestations as X rays and radio emissions of cosmic origin. However, this review is concerned chiefly with intensities in the electromagnetic octave designated the "visual" spectrum.

For orientation we have plotted in Figure 1* the distribution, according to spectral class, of stars brighter than visual magnitude 6. The upper part of the plot shows the wavelength corresponding to peak intensity assuming that the superficial temperature of a star may be treated as a black body temperature. There is an observationally favored domain between 3000A (the atmospheric cut-off) and 8000A where the hydroxyl nightglow bands become sufficiently strong to interfere with astronomical observations. Within this spectral region, stars of classes A, F, G, and K, comprising 75% of the bright stars, have their peak intensities. Even allowing for the likelihood of observational bias in Figure 1 in the use of the bright stars relative to a population of all the

* Taken from Trumpler and Weaver (1962), Table 4.4.

stars in our galaxy it is apparent that any systematic data for the visual region should be reasonably representative of the stellar sample.

The complications involved in piercing the terrestrial nightglow haze in order to gain knowledge of non-terrestrial light sources is apparent from an inspection of Figure 2 showing the distribution of many of the emission features of the glow. A discouraging fact is that even in the regions between prominent emission lines and bands there is no known wavelength in which there is no nightglow continuum ---- and such a continuum cannot be discriminated against with respect to zodiacal light or integrated starlight by decreasing the band pass of a filter.

III. THE PLAN OF THE PAPER.

It is proposed to treat the problem of faint optical radiations in the universe as follows: we shall select a spectral region (5300A) near the center of the visual sensitivity curve. For this wavelength we propose to examine surface brightnesses of the "night" sky proceeding from intergalactic to interstellar to interplanetary space and then to the earth's surface.

At the earth's surface we shall then introduce the wavelength as a parameter and discuss the nature of the nightglow throughout the visual spectrum with some comments on its nature in the near infra-red.

IV. THE INTERGALACTIC OBSERVER AND INTEGRATED LIGHT FROM EXTRA GALACTIC SOURCES

In order to obtain an approximation of the brightness of the "sky" in intergalactic space, we make the following assumption:

There are 10^6 galaxies uniformly distributed throughout a sphere of radius 300 megaparsecs (9.27×10^{26} cm) each having 5×10^{10} stars (suns).

Let ρ = space density of the individual sources which will be treated as points (in cm^{-3}),

r = the radial distance in cm,

R = the radial distance to the boundary of the sphere in cm,

B_0 = the flux from each galaxy, and

L = the brightness for an observer in the center of the sphere in flux cm^{-2}. $sphere^{-1}$.

Then

$$L = \int_0^R \frac{4\pi r^2 . \rho . B_0 . \ dr}{r^2}$$

$$= 4\pi \ B_0 \ \rho R .$$

In our example $= 5 \times 10^{10}$ suns, $\rho = 3 \times 10^{-76}\ cm^{-3}$,
$R = 9.27 \times 10^{26}$ cm

And $L = 3.907 \times 10^{-11}$ suns per sphere.

It is of interest to convert this to S_{10} (vis) units*:

$$L = \frac{3.907 \times 10^{-11} \times 4.875 \times 10^{14}}{4.1253 \times 10^{4}} = 0.46\ S_{10}\ \text{(vis) units}$$

or about 1/600 the brightness of the terrestrial zenith sky on a moonless night. The energy flux of visual light in intergalactic space is

5×10^{-5} erg. sec^{-1}. cm^{-2},(from a sphere)

and the energy density

7×10^{-15} erg. cm^{-3}. It is of interest to note that the energy density of starlight in our galaxy and that of cosmic rays are both about 10^{-12} erg • cm^{-3} (Allen, 1963)

V. THE INTERSTELLAR OBSERVER AND INTEGRATED STARLIGHT

The first telescopic observers of the Milky Way were thrilled by the evidence that what seemed like a band of light could be resolved into numerous closely-packed individual stars. This paper is really an historical retrogression to the more primitive view of the synthesis of the individual stars into an integrated surface brightness. But it will be instructive to examine in passing, some of the results of those who have "counted" stars in order to gain an insight into the structure of our galaxy.

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* The sun, m (vis) = −26.72, is 4.875×10^{14} as bright as a tenth magnitude star. The S_{10} (vis) unit is "number of 10th magnitude (visual) stars per square degree" hence the division by 41, 253 (the number of square degrees over a sphere).

To "count" the stars individually is certainly a supra-human task (there are about 10^9 stars brighter than photographic magnitude 21). Early in the 20th century, J. C. Kapteyn initiated a cooperative international program of star counting in Selected Areas, 206 of them, arranged systematically over the sky. The simplest measurement was that of the total number of stars in each Selected Area for longer and longer exposure times corresponding to fainter and fainter limiting magnitudes.

In a classical report*, details of such a study are given. An idea of the size of the statistical sample for the study of 139 Selected Areas** in the Mount Wilson program may be judged from the fact that a total of 65,683 stars was measured to approximate limiting photographic magnitude 18. The total number of stars over the sky to this same limiting magnitude comes to about 3×10^8 so the sample is $6.5683\times10^4/3\times10^8 = .00022$ of the total. Another estimate of the sample size may be obtained from the fact that the region measured on each plate was 0.1154 square degree compared with the 41,253 square degrees over the sky. Thus the sample is

$$(0.1154 \times 139)/41253 = 0.00039 \text{ of the total.}$$

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* Seares, van Rhijn, Joyner and Richmond, (1925), Mount Wilson Contribution number 301, referred to hereafter as MW 301.

** The extreme southern declination of the Mt. Wilson program was -15°, hence the omission of Selected Areas 140-206.

It may be anticipated that the sampling method employed will be useful in delineating the gross features of our galactic system but will almost certainly break down in any attempt to depict detailed structure. Kapteyn was able to synthesize the results of the then available statistical results into a generalized morphological picture of the "Kapteyn Universe" of our galaxy. Emerging from the ensemble of numbers is a flattened ellipsoid of revolution of stars of diameter some five times its thickness (see Table 2).

One of the important considerations for the purposes of the present discussion is the non-central position of the sun in the galaxy. We find ourselves close enough to the galactic plane to see the Milky Way as a circle in the sky but far enough from the center of the ellipsoid to make the part of the Milky Way seen in the direction of the center significantly brighter than that in the opposite direction.

The temptation to continue a discussion of galactic structure from star counts is very strong indeed.* The grandeur of the morphological picture is both overwhelming and humbling. But we must now admit that the subject was introduced for the purpose of giving a general basis for the estimation of the contribution of integrated starlight to the nocturnal sky to which subject we now return.

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* The Selected Areas have been subjected to concentrated studies of stellar parallax, proper motion and radial velocity as well as photometric star counts. The star counts have been stressed in this paper because they lead directly to the matter of the light of the night sky.

The star counters always refer their counts to "numbers per square degree" of the sky and for convenience we shall follow them in adopting as a unit for the integration of radiation from the star background the "number of equivalent tenth magnitude stars per square degree" which will be designated S_{10} (vis) or S_{10} (pg) depending on whether we use the visual or the photographic magnitude scales.

Some gross results of the counts themselves are shown in Table 3 and Figure 3. An examination of Figure 3 shows a number of features. The scales have been chosen so that a logarithmic difference of 2 (factor 100) in the ordinate A(m), the number of stars per magnitude interval, is the same as a magnitude difference of 5 in the abscissa, a factor of 100 in the brightness. Thus, if the slope of an observed curve is greater than 1.0, the number of stars increases more rapidly than their brightness decreases and the total contribution to the integrated starlight increases. Similarly a slope less than 1.0 indicates a declining contribution for successive magnitude intervals. The inflection at slope = 1.0 corresponds to the maximum contribution.

The curve for b(galactic latitude) = 90° indicates a maximum near m(pg) = 8; that for b = 0° near m(pg) = 12. The upper curve of Figure 3 is a plot based on the star counts over all values of the galactic latitude. In order to refer them to the entire sky the values per square degree have been multiplied by 41,253 (the number of square degrees over a sphere) to give the T(m) in the last column of Table 3.

Many of the tables of star counts record not the number of stars, A(m), within a given magnitude range but the cumulative number, N_m, brighter than a given magnitude, m. Such a table was published

by P. J. van Rhijn (1925) in the form of entries of log N_m from m = 6.0 to 18.0 for every 10° of galactic longitude, l, and for galactic latitudes, b, of 0°, -2°, ±5°, ±10°, ±15°, ±20°, ±30°, ±40°, ±50°, ±60°, ±70°, and ±80° (10, 296 entries for 792 regions in the sky). It is apparent that the entries for a given region must be significantly smoothed since the basic information is the star counts for the 206 Selected Areas. The reader is referred to a paper by Roach and Megill (1961) for a numerical integration of the total star-light deduced from the Van Rhijn (Groningen Publication 43) tables. Total integrated starlight deduced from both GR 43 and the MW 301 contributions is shown plotted in Figure 4 from the entries of Table 4. For low galactic latitudes , the GR 43 results are systematically higher than those from MW 301 but the discrepancy between the two investigations

is trivial for high galactic latitudes.

This review of the available information on star counts has been made for the purpose of introducing an isophote map depicting the total starlight over the entire sky (figure 5), based on the star counts in GR 43. The map has been used extensively by photometric observers but should probably be considered as too crude for detailed studies especially near the galactic equator where the scale is in question (figure 4) and the resolution is doubtful. Some comments on the map will perhaps indicate the reservations that should be exercised in its use.

(1) The great rift in the Milky Way, so apparent to even a casual observer is not shown,

(2) The maximum brightness is at b = -1°, l = 242° ($\alpha = 9^h\ 20^m; \delta = -52°$) in the constellation of Carina. This portion of the Milky Way is almost 90° away from the bright star cloud in the constellation Sagittarius which together with the nearby cloud* in Scutum is generally considered the brightest part of the Milky Way.

The writer** is engaged in the preparation of an isophote map of the Milky Way based on observations with a photoelectric photometer. What is in principle a straightforward measurement is severely affected by two technological problems, the absolute calibration of the photometer and the proper allowance for the zodiacal light and the night airglow. Two / earlier Milky Way maps might be mentioned. Elvey and Roach [1937] (LVR) published one in their attempt to establish the existence of the so-called galactic light, the excess of the observed intensities over the mean star count intensities based on Bottlinger's [1932] integration of MW301.

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* The use of the word "cloud" in connection with the great concentration of stars in Sagittarius and Scutum is reminiscent of Barnard's inspired description "the stars pile up in great cumulus masses like summer clouds." The writer recalls that as a young observer he was once fooled by the Sagittarius cloud coming up in the east to the extent of recording in his observing book the existence of meteorological clouds. The illusion was soon resolved as the night progressed.

** In collaboration with L. L. Smith (1964b)

More recently Elsässer and Haug (EH) (1960) have published isophote maps of the Milky Way based on their photoelectric observations. In Figure 6 are shown the relationships deduced by Roach and Smith (RS) between the LVR, the EH and the GR43 investigations and their measured Milky Way intensities. Relative to the measurements of RS the LVR intensities are high and the EH ones low. The relationship between the GR43 integrations and the RS observations will be discussed in the next section.

VI. THE GALACTIC LIGHT AND THE INTERSTELLAR DUST

The interstellar region is not empty space. There are some atoms present--enough to produce absorption lines over astronomical distances. That there is also some dust concentrated toward the galactic plane is indicated. In support, we may mention as evidence:

(1) Stars near the galactic equator are reduced on an average of 0.67 magnitude (photographic) per kiloparsec of distance from the solar system,

(2) They are diminished by 0.35 magnitude (visual) per kiloparsec,

(3) The so-called "color excess," the reddening measured by the difference between the photographic and visual effects, is 0.32 magnitude per kiloparsec,

(4) Extra-galactic nebulae are, in general, not observed near the galactic plane, the so-called "zone of avoidance."

Dust not only obscures and reddens the light from a particular star but also scatters the light from all the stars, some of the scattered light being in the direction of an observer. It is thus possible to have a situation in which an observer in a particular location (such as the solar system) may find the total astronomical light from a particularly dusty region to be greater than the total inferred from the summation of the light from all the stars.* And to state an apparent paradox: the heavier and blacker the dust cloud the greater may be the excess due to such scattered light.

About 1937 two papers appeared independently on the subject: one theoretical and one observational. The numerical agreement between the theoretical prediction for the case of our galaxy and the observations was, as it turned out, probably "too good to be true." Wang Shih-Ky (1937) derived a theoretical value for the diffuse galactic light from a dusty region of about 1/2 the average light impinging on the region over the entire sphere surrounding it. According to Seares et al (1925) the total intensity of starlight over the sky is equal to that from 577 stars of photographic magnitude 1.0 or 56 stars of magnitude 10.0 per square degree. Thus Wang's prediction calls for a galactic light of about 28 S_{10} (ph). Elvey and Roach (1937) concluded from their measurements that the mean galactic light in the Milky Way was about 55 S_{10} (ph) units,

twice that predicted by Wang Shih-Ky but, considering the difficulty of the measurement, it was considered at the time that theory and observation were reconciled in terms of a galactic dust cloud which obscures stellar

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* The scattering by the dust is similar to that experienced in the solar system leading to the zodiacal light to be discussed later.

members of our galactic system as well as more distant extra galactic nebulae located in the line of sight behind the cloud and at the same time scatter the light from all the stars to make the dark cloud grey.

Henyey and Greenstein [1941] examined the galactic light problem by making a photometric study of two regions of the Milky Way, one in the constellation Cygnus and the other in Taurus-Auriga. Stars brighter than visual magnitude 15 were excluded. Their interpretation resulted in numerical values similar to those reported by LVR for the same regions. The agreement may be fortuitous since the two investigations used different star count data: LVR used Bottlinger (MW301); HG used van Rhijn (GR43)*.

It is the opinion of the writer that the question of the existence of the galactic light should be reexamined. The reasons for this opinion are as follows:

(1) There is evidence that the absolute calibration of Elvey and Roach was too high and that their measured intensities should be multiplied by 0.7 (Roach et al, 1954). Such a correction would reduce the deduced galactic light.

(2) The predicted intensities of integrated starlight in the vicinity of the Milky Way are very uncertain, as witness the discrepancy between the MW 301 and GR 43 results.

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* See figure 4 for the systematic difference between the Bottlinger integration of Mt. Wilson 301 and that based on Groningen 43.

(3) The estimation of the galactic light should be based on photometric measurements coupled with star counts of the region in question rather than mean star counts of a large sample.

The problem has been brought to the fore recently in a paper by Elsässer and Haüg (1960), already referred to. The general intensity level observed by them is much lower than that of Elvey and Roach and even than that predicted by the GR 43 star counts. By comparing their measurements with the star count predictions from MW 301 (much lower than those for GR 43) it is still possible to infer a galactic light. Proceeding in this way van Houten (1961) has concluded that the galactic light in the galactic plane is about 12 S_{10}(ph) units. But, if the higher intensities of GR 43 are taken, the galactic light comes out to be negative, an obvious impossibility. There is evidence that the Elsässer-Haug absolute calibration may have been low which further adds to the difficulty.

Referring again to Figure 6 we note that Roach and Smith found that their measured star background intensities were $1/0.794 = 1.26$ times those predicted by the GR 43 star counts*. This would correspond to a galactic light of $(1.26 - 1.00) \times 172 = 45$ S_{10}(ph) units for galactic latitude 0°.

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* Roach and Smith used star count integrations for specific regions of the sky rather than average values.

The establishment of reliable values for the brightness of the galactic light originating in scattered star light from galactic dust is a problem of fundamental interest. It is the writer's opinion that all published values, including those to which he has contributed, are provisional.

VII. THE ZODIACAL LIGHT AND INTERPLANETARY DUST

In the previous section we introduced evidence that, in a distance comparable to the dimensions of our galaxy, there is enough line-of-sight dust to (a) seriously weaken or even obscure light sources behind it and (b) scatter the light from all the stars.

Turning to our solar system we must recognize that the amount of solar system line-of-sight dust in distances measured in Astronomical Units is not enough to give any significant or measurable contribution to the extinction of stars seen through it. Hence, <u>relative</u> to the light flowing onto it, the amount of scattered light from interplanetary dust must be very small. But in <u>absolute</u> terms, the nearness of the very bright sun makes it pertinent to look for dust scattering effects even if the total line-of-sight dust in the solar system might be as small as 10^{-8} times that in galactic space.* These general considerations lead us to the not too surprising observation that there is indeed evidence for the existence of such interplanetary dust in what is known as the zodiacal light which in its brightest portion, as observable

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* One star (the sun) at a distance of 1 Astronomical Unit is about 10^8 times as bright as the totality of all the non-solar starlight as seen from the earth.

from the earth's surface is about 10^{-9} times the surface brightness of the sun and some 100 times the integrated brightness of the starlight.

Even in the portions of the sky where the zodiacal light is at its weakest it is about equal in brightness to the average starlight intensity. This brings us to one of those "accidents" which makes life so interesting on our planet—if the dust concentration in the solar system were say ten times its actual value we should have a night sky so bright that astronomical features such as the Milky Way would be visually lost in the zodiacal light haze.

The zodiacal light has long been known to be concentrated near the ecliptic. In figure 7 is shown, on a linear scale its intensity in the ecliptic as it can be measured from the earth's surface for elongations, ϵ, extending from 30° to 180° (gegenschein) based on a recent study by Weinberg [1963]. In figure 8 is shown, on a double logarithmic scale the variation of the intensity in the ecliptic to the sun's limb including (a) observations of the F-corona (presumed to be the zodiacal light in line of sight close to the sun), (b) the zodiacal light and gegenschein from Roach, Pettit, Tandberg-Hannsen and Davis [1954] and from Roach and Rees [1955], and (c) measurements of the zodiacal light in the domain $30° > \epsilon > 5°$ based on the 1954 high altitude eclipse measurements of Blackwell as recorded in Table III of Ingham [1961].

The evaluation of the brightness of the zodiacal light as a function of ecliptic latitude becomes progressively more and more difficult as the pole of the ecliptic is approached because of the uncertainty introduced in the subtraction of the other principal components of the light of the night sky--the airglow and the integrated starlight. In figure 9 is shown a plot of the brightness of the zodiacal light for $\lambda-\lambda_{\odot} = 90°$, from the ecliptic ($\beta = 0°$) to the pole ($\beta = 90°$) based on a current study by Roach and Smith [1964b]. It is worthy of note that at the ecliptic pole the brightness of the zodiacal light is approximately

$100\ S_{10}$(vis) units.

The interpretation of the physical composition of the interplanetary medium responsible for the zodiacal light is facilitated by evaluations of both its brightness and its polarization. Within the past decade the tendency has been to ascribe a major part of the polarization to "dust" particles and a minor part to interplanetary electrons.

In figure 7 we show a plot of the polarization of the ecliptic zodiacal light as a function of elongation angle from the sun based on the work of Weinberg [1963]. Current analyses favor an interpretation based on a space density of particles of 5×10^{-21} ____ gram $\cdot cm^{-3}$ and an electron density of some tens and probably not greater than 50 electrons cm^{-3}. The reader interested in such physical interpretations is referred to Ingham (1961), to Elsässer [1963] as well as to the paper by Weinberg already mentioned. Early studies of the physicial nature of the zodiacal dust cloud were made by Allen (1946) and by van de Hulst (1947).

VIII. SOME COMMENTS ON EXTINCTION AND SCATTERING BY COSMIC DUST

Since the zodiacal cloud is sensibly flattened toward the ecliptic plane the question arises whether there may be a "zone of avoidance" for objects observed in the direction of the ecliptic. Looking away from the sun, assuming that the zodiacal cloud continues with its terrestrial density out to the vicinity of the orbit of Pluto ($\sim$40 A.U.), the transmission through such a cloud would be 0.9999. The weakening by 0.0001 is probably not detectable.

The "zone of avoidance" for the observation of extragalactic objects near the galactic plane constitutes compelling evidence that there is a significant absorbing medium in that plane. The localized dark "clouds" in the Milky Way and the prominent rift of the Milky Way suggest that we are dealing with a dusty type of absorption which can be put into quantitative terms by the estimate of the <u>mean</u> weakening of stars in the vicinity of the galactic plane of 0.35 mag. (visual) per kpc (3.09×10^{21} cm). Such a weakening corresponds to a transmission of 0.725 for an object at a distance of 1 kpc or $\beta = 1.0 \times 10^{-22}$ cm^{-1} in the expression $I/I_o = e^{-\beta R}$. This corresponds to a dust density only 0.0067 that of the zodiacal cloud but the opacity introduced is significant over galactic distances. The sun is some 8 kpc (2.47×10^{22}cm) from the center of our galaxy. The transmission of visual light over 8 kpc is down to 0.09 so it appears that we "see" the galactic center only very dimly. The mean weakening of photographic light ($\sim$4500 A.U.) is about 0.67 magn per kpc ($\beta = 1.965 \times 10^{-22}$ cm^{-1}). Over 8 kpc this corresponds to a transmission in the photographic part of the spectrum of only 0.008 so, by photography, we are really blind so far as the galactic center is concerned.

In the anti-center direction the obscuration is still serious and we owe much of our knowledge of the detailed galactic structure in this region to the brilliant work of the radio astronomers who fortunately are not inhibited in their studies at the longer radio wave lengths by the interstellar dust.

The extent of the galactic dust cloud perpendicular to the galactic plane is relatively small (perhaps 200 to 300 parsecs), thus we are fortunately able to plumb the extra-galactic universe out to at least 10^{28} centimeters*.

The role of cosmic dust as an absorber gives way in the present discussion to its associated property of scattering. To a first approximation the two phenomena are related. If I is the observed surface brightness, $I_\circ$ the brightness in the line of sight on the far side of a dust "cloud," and L is the flux of light falling on the cloud from all directions, then

$$I/I_\circ \approx e^{-\pi \Lambda^2 N.R.} = e^{-\beta R}$$

$$I/L \approx \gamma\,(1-e^{-\beta R})$$

where γ is the albedo of the particles, Λ is their radius** and N is their number density in cm^{-3}. In the

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* The Estimated Distance to Object 296 in the Third Cambridge Catalogue of Radio Sources (3C296) = 10^{10} l.y. = 3.1×10^9 pc = 9.5×10^{27} km., $\log_{10} R = 27.98$.

** We here assume for simplicity that all the particles have the same radius and that their geometrical cross section is equal to their effective cross section. For an authoritative discussion of the role of dust in extinction and scattering the interested reader should consult the book on "Light Scattering by Small Particles" by H. C. van de Hulst (Wiley, 1957).

case of perfect reflectors ($\gamma = 1$)* and a uniformly illuminated cloud ($I_\circ = L$) we have

$$I/I_\circ = e^{-\beta R} = 1 - I/_L$$

In other words, the extinction of the direct beam is compensated by the scattering from the light impinging on the cloud from the sphere surrounding it. A case in point is the galactic light already discussed which is the scattered light from galactic dust whose extinction effects have been well established.

A contrasting case is that of the zodiacal light due to a dust cloud so tenuous that its extinction is trivial. The fact that it is easily observed is due to the great intensity of its illuminator, the sun. Even though the total sunlight scattered by the zodiacal cloud is only about 10^{-6} of the sunlight falling on it this is sufficient to provide the light of the night sky with its principal component.

We present in Figure 10 and Table 5 a general representation of dust in the cosmos with particular reference to its extinction and scattering properties. The principal diagonal in Figure 10 with a slope of -1 corresponds to the case of $\beta = \frac{1}{R}$ where $I/_{I_\circ} = 0.368$ and $1 - I/_{I_\circ} = 0.632$. It thus marks the region where a transmitted pencil of light is significantly weakened and scattering of a general illumination is enhanced. The region to the left of the diagonal is designated "transparent" and that to the right "opaque." There are two ways in which a physical situation may degrade from a transparent

*These idealized assumptions are used for general illustrative purposes. It is, of course, not likely that the albedo, in a natural case, will be unity nor will the geometrical cross section be equal to the effective cross section. See van de Hulst (1957).

to an opaque condition: (a) the density of the dust may increase pushing the point upward, or (b) the path length may increase moving the point to the right.

In the last column of Table 5 is shown the distance required for a given dust concentration to result in a decrease of a pencil of light to 1% of its original intensity. In three of the four cases listed we note that we are saved from a black prison by the fact that in each case the extent of the dust is limited to distances such that $\beta << \frac{1}{K}$. In the fourth case, the galactic dust, we are not so fortunate in the plane of the galaxy where $\beta \approx 1/K$ but we can escape into intergalactic space via light beams away from the galactic plane where the flatness of our galaxy results in small extinction effects.

VII. THE EARTHBOUND OBSERVER AND THE NIGHT AIRGLOW. THE CONTINUUM.

Evidence has grown that there is a component of radiation in the night sky of terrestrial origin which cannot be accounted for as due to the discrete emissions shown in figure 2. It has come to be called a "continuum" though it may be the result of a large number of discrete emissions too faint to be recorded even on long exposure spectrograms.

One bit of evidence suggesting the existence of such a nightglow continuum is based on an application of the so-called van Rhijn method. Van Rhijn [1921] called attention to the fact that a uniform emitting layer at a height, h, above the earth's surface will result in a systematic increase in intensity toward the horizon for an observer on the

Earth's surface. In the absence of a lower atmosphere the ratio of intensity, I_z, at a zenith distance, z, to that at the zenith, I_o, is given by

$$I_z / I_o = V_z = \frac{1}{\sqrt{1 - \left(\frac{R}{R+h}\right)^2 \sin^2 z}}$$

The interposition of the atmosphere between the emitting layer and the observer significantly modifies the effect so that the observed ratio V_z' is always numerically smaller than V_z.

In principle it is possible to deduce the height of the emitting layer from systematic observations as a function of zenith distance but in practice the accuracy of such height determinations has been poor due to difficulties associated with (1) the extinction and scatter of the lower atmosphere, (2) the lack of uniformity of intensity of the emitting layer over the sky and (3) the difficulty of allowing for the contamination* of the observations by the astronomical light passed by the filter. For a definitive study of these problems the reader is referred to a paper by Roach, Megill, Rees and Marovich (1958).

Although the use of the van Rhijn approach in matters of quantitative finesse such as the deduction of emitting layer heights is not very fruitful, nevertheless the qualitative prediction of a systematic increase in intensity toward the horizon for such an emitting layer is helpful. As long ago as 1909 Yntema (1909) identified what he called

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* To an airglow observer the astronomical light is a contamination. In the context of this paper, on the contrary, the airglow may be considered a contamination.

Earthlight by such an interpretation of systematic observations of the night sky. Roach and Meinel (1955) have attempted to discriminate between the upper atmosphere and astronomical components and to estimate the percentage contribution of each in a given set of observations. Their method is illustrated in Table 6 and Figure 11. In the example we deduce an upper atmosphere component of about 30% of the total.

The predicted values of $V'z$ are based on an assumed extinction coefficient of 0.142 atm^{-1} and an assumed scattering coefficient of 0.121 atm^{-1}. In the case of the 100% astronomical calculation it was assumed that the astronomical light (integrated starlight and zodiacal light) was uniformly distributed over the sky. Although this is probably a reasonable assumption for the integrated starlight if many observations are used during which the Milky Way will not favor any particular zenith distance, it is not a good approximation for the zodiacal light which is systematically brighter toward the horizon. Thus the percent of upper atmosphere light deduced in the last column must be considered as an upper limit.

A dramatic indication of the existence of an airglow continuum has been obtained by the American astronauts. They have all reported that there is an easily visible glow on the night side of the earth appearing as a sort of annulus separated from the solid earth horizon. Analysis of the height of the layer places it in the 100 - kilometer region. The intensity is too great to be accounted for by the known discrete emissions (including the 5577A line) and is thus in large part ascribable to a general continuum (Koomen, Gulledge, Packer and Tousey, 1963). Its visibility from a satellite (and not from the ground) is due to the favorable circumstances of a long grazing line of sight through the emitting layer (a 35-fold increase of intensity) plus the absence of lower atmosphere extinction.

Astronaut Gordon Cooper was especially successful in observing the night airglow layer both visually and photographically during his May 16, 1963, orbiting in satellite Ma-9 (Faith 7). In figure 12 is shown one of his photographs, a ten-second exposure showing a night airglow band above the earth, the latter being visible by virtue of the illumination from a quarter moon. Color photographs by Cooper show that the night airglow layer appears green in contrast with the bluish cast of the moonlit earth.* An analysis of nine of Cooper's photographs by Gillett, Huch and Ney (1964) gives us the height of the center of the airglow band above the earth's surface, a mean of 88 kilometers with extreme values ranging from 75 km to 111 km.

IX. THE NIGHTGLOW. ATOMIC AND MOLECULAR EMISSIONS.

If the domain of interest is now expanded to include the entire visual spectrum we come to the matter of atomic and molecular emissions originating in the Earth's upper atmosphere. A definitive review of the nightglow should include discussions of such matters as temporal and spacial changes, emission heights and excitation mechanisms.

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* "Practical" men have, on occasion, categorized pure research as being concerned with such impractical matters as "why is the grass green?" They may now add to their list of useless investigations "why is the night sky green?"

Our purpose here is to give a brief description of the photometric nature of the nightglow. We refer the reader interested in a more detailed discussion to review papers* and the authoritative book by J. W. Chamberlain (1961). In Table 7 we record the principal nightglow emissions as presently known. In Figure 12 they are shown plotted as functions of wave-length and of emission height.

Historically the emissions [OI] 5577, [OI] 6300 -64 and NaI 5890-96 came first to the attention of observers. Later the Herzberg bands were identified as important contributors in the 3000A to 4000A domain. Energetically the most conspicuous known component of the nightglow is the extensive system of rotation-vibration bands due to the hydroxyl (OH) radical. The hydroxyl bands are listed in Table 8 in order of increasing wave-length. The absolute intensities are shown both in the table and in Figure 13.

Attention is called to the fact that the night airglow shown as a component in the zenith skies of Fritz Peak and Haleakala (Figure 14) is based on a filter transmitting a narrow band near 5300A. The spectral region was chosen to avoid prominent nightglow emissions (one of the weak hydroxyl bands is however included). The airglow transmitted by the filter is largely what we have referred to in the previous section as a "continuum."

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* See for example Roach (1963).

Obviously, if the purpose of an investigation is the study of specific nightglow emission features, filters will be chosen to center on the emission or, alternatively, the investigation may be carried out by spectroscopic means. The spectrographic method suffers from the fact that, with the spectrographs that have been employed, exposure times of the order of an hour are needed to bring out the emission features. The spectrograph slit may include a large slice of the sky (in one design a vertical circle from horizon to horizon). In filter photometry the flux of light on the cathodes of photoelectric detectors used in conjunction with telescopes of modest aperture is sufficient that an integration over a fraction of a second yields a reliable photo-current. The entire sky can be surveyed in a few minutes so that several complete sky coverages can be made by a filter photometer during a single spectrographic exposure and, as a consequence, most of the systematic work on the nightglow has been done with

photometers. If the isolating filter used in a photoelectric photometer could be as narrow as a spectrograph slit an emission feature of the nightglow could be reasonably discriminated with respect to the astronomical background (integrated starlight and zodiacal light). The available interference filters are sufficiently narrow that one centered on an emission line such as 5577A can result in as much as 75% of the total zenith reading due to the emission and 25% to the background.*

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* A technological advance of great importance to nightglow observers was the development of a birefringent filter which discriminates between an emission line and a background continuum. See Dunn and Manring [1955]; also Roach, Megill, Rees , and Marovich [1958].

The general conclusion emerges from this discussion that the photometric observer of the light of the night sky is necessarily concerned with all three components in the analysis of his data explaining why the present paper which was originally planned as a discussion of the zodiacal light was expanded into a more ambitious undertaking.

X. SUMMARY

We bring together our general results in two figures. Figure 14 portrays the resolution of the light of the night sky into its three principal components based on a series of zenith observations extending over a year at the two stations: Fritz Peak in Colorado, U. S. U., (latitude N39°.9, longitude W105°.5) and Haleakala in Hawaii, U. S. A. (latitude N20°.7, longitude W156°.3). The observations are from a current study by Roach and Smith (1964a) using photometers centered on wavelength 5300A. With respect to sidereal time the airglow continuum is a constant*. The two Milky Way traverses are conspicuous features of the integrated starlight curves. The variation of the zodiacal light is the result of the variable ecliptic latitude of the zenith throughout the year. A refined analysis of the data, not shown in the plot, gives a further variation of the zodiacal light as a function of $\lambda - \lambda_{\odot}$, the differential ecliptic longitude between the zenith and the sun. The zodiacal light

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* Local time changes in the airglow may vary but such changes are averaged out with respect to sidereal time.

is the brighter of the three components except when the Milky Way is in the zenith. The zodiacal light tends to be systematically brighter toward the horizon so that it is definitely the most prominent of the three for the sky as a whole.

The interrelationships of the constituents of the light of the night sky are shown from a different point of view in Figure 15 where the ordinate is logarithm of the surface brightness and the abscissa is logarithm of the distance or extent. Moving downward in the plot the features of the night sky appear below the line corresponding to the end of twilight. The brightness of the nightglow, the zodiacal light and gegenschein, the integrated starlight and galactic light are comparable (on the logarithm scale) but one is impressed with the vastly different linear distances in connection with the several phenomena. The nightglow is a terrestrial phenomenon having a thickness of about one atmospheric scale height ($\log R \approx 7$). The zodiacal light is an interplanetary phenomenon with a characteristic dimension of one astronomical unit ($\log R \approx 13$). The integrated starlight from our galaxy has a characteristic maximum dimension of some 30 kpc ($\log R \approx 23$). Finally the extra galactic nebulae which collectively contribute much less than 1% of the light of the night sky are at distances as much as $\log R \approx 28$. They can be photographed individually in spite of the competition of the sky background and in spite of the hazard of extinction by intervening dust.

In the preparation of this report the writer has been impressed with the confluence of several circumstances that make possible the observation of the universe in the visible part of the spectrum. Any one of several contingencies might have made such observations impossible.

Let us consider the matter of contrast. The prime example here is the bright (but beautiful!) day sky which prohibits serious daytime study of the astronomical sky. There follows, during a diurnal terrestrial rotation the period of twilight which under the best of circumstances lasts a little less than 1 1/2 hours but which, during the local summer, in the vicinity of polar regions persists all night. The obliquity of the ecliptic is sufficient to make a stimulating annual sequence of seasons but small enough to keep the twilight period of reasonable duration over a good portion of the earth.

A hazard narrowly averted is that due to the interplanetary dust cloud leading to the zodiacal light. The concentration of dust is very small indeed (figure 10) so that an increase by a factor of ten would be trivial in terms of the constitution of the solar system*. But such an increase would result in a night sky so bright (average zodiacal light 2000 S_{10} (vis) instead of 200) that the Milky Way would be difficult so see and the airglow difficult to measure. The aesthetic gain in

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* It is of interest to speculate that during the history of the solar system the interplanetary dust concentration may have been significantly greater than at present.

a rather spectacular zodiacal light pattern over the sky would hardly compensate for the loss from the absence of the details of our galactic universe. The effect of such an enhanced zodiacal light would correspond to that experienced in a planetarium when the operator adjusts the rheostats to bring on dawn and the celestial objects disappear.

A permanent twilight that would have the same effect would be due to the hydroxyl nightglow if (a) it were concentrated in the visible part of the spectrum rather than in the near infra red or if (b) the human eyes were sensitive in the near infra red.

The narrow escape from the cosmic ignorance that would have resulted from a situation in which the observer found himself in a less favorable environment is well illustrated by the "zone of avoidance" of extra galactic nebulae in the vicinity of the Milky Way plane. If our galaxy were not highly flattened so that its extent perpendicular to the plane is sufficiently small to permit an observational window outward we would not have been able to photograph the extra-galactic objects and we would have been content with a rather restricted concept of a universe consisting of a single galaxy. The same dire result would have occurred if the sun to which our planet is attached were more deeply embedded in the galactic dust near the galactic center. Thus we find compensation for our non-central location.

There can be little doubt that human ingenuity would in time have overcome any or all of the above circumstances as the radio astronomers have done by changing the exploring frequency so as to avoid the difficulties. But this would have taken time, especially in the absence of the stimulation of the knowledge gained by visual and photographic observations. It is likely that the time lag would have been sufficient that the present review could not have been written by the present author. It may be conjectured whether other astronomers on other planets are as fortunate or whether, after all, this is "the best of all possible worlds."

LEGENDS FOR FIGURES

Fig. 1. Distribution of the bright stars according to spectral class (below). Wavelength of peak intensity of starlight according to spectral class (above).

Fig. 2. The principal emission features in the night airglow arranged roughly according to their emission heights in the atmosphere.

Fig. 3. Logarithm of the number of stars per magnitude interval as a function of the apparent photographic magnitude (from Table 3).

Fig. 4. The variation of integrated starlight brightness with galactic latitude. The systematic difference between the integrations based on GR43 and MW301 for low galactic latitudes is apparent by comparison of the two lower curves.

Fig. 5. Total integrated starlight in number of tenth magnitude (visual) stars per square degree in galactic coordinates.

Fig. 6. Plots showing the relationships between the observational measurements of integrated starlight of Elvey and Roach [1937], Elsässer and Haug [1960] and those of Roach and Smith (1964a). Also the integrated starlight deduced from the Groningen 43 star count tabulations [Roach and Megill, 1961] is shown plotted against the recent Roach-Smith measurements.

Fig. 7. The brightness and polarization of the zodiacal light in the ecliptic from elongation angles ε, $30°$ to $180°$ according to Weinberg [1963]. Note the slight increase in the brightness (the gegenschein) as the counter-sun position is approached ($\varepsilon = 180°$).

Fig. 8. The brightness of the zodiacal light in the ecliptic versus the elongation angle, ε, from the sun's limb (F-corona) to the gegenschein (note the log-log scale). Sources of information are Blackwell as quoted by M. F. Ingham [1961) from the solar limb to $\varepsilon = 30°$; Roach, Pettit, Tandberg-Hannsen and Davis [1954] for $100° > \varepsilon > 30°$ and Roach and Rees [19] for $180° > \varepsilon > 100°$.

Fig. 9. Variation of the brightness of the zodiacal light from the plane of the ecliptic to the ecliptic pole for $\lambda - \lambda_{\odot} = 90°$.

Fig. 10. Graphical representation of the occurrence of dust on the cosmic scale. See the text for the significance of the ordinate and abscissa scales.

Fig. 11. Variation of observed increase toward the horizon of the brightness of the night sky for a wavelength of 5300A based on the average results over four nights at Haleakala. The observations (dots) can be compared with predicted variations based on assumed percentages of upper atmosphere nightglow component from 0% to 100%.

Fig. 12. A ten-second exposure made by Astronaut Gordon Cooper from an orbiting satellite on May 16, 1963, showing a luminous nightglow band distinctly above the earth's surface. From Gillett, Huch, and Ney (1964).

Fig. 13. Above: Distribution of intensities and wavelengths of the rotation-vibration bands of OH in the nightglow; observed to about 1.5μ and predicted for wavelengths longer than 1.5μ. Also, the absolute intensity of the thermal radiation from the lower atmosphere for a temperature of 275°K, a slit width of 0.1μ, and an emissivity of 0.3. Below: The transmission of the lower atmosphere versus wavelength.

Fig. 14. The variation of the three principal constituents of the light of the night sky with sidereal time for the stations Fritz Peak and Haleakala.

Fig. 15. Graphical representation of the brightness of components and features of the day and of the night sky with the cosmic occurrence indicated by the distance or extent of each along the abscissa. Note the log-log scales.

REFERENCES

Allen, C. W. 1963, Astrophysical Quantities (2d Edition) p. 255 (Athlone Press)

Allen, C. W. 1946, M. N. R. A. S. 106, 137.

Bottlinger, K. F. 1932, Zs. F. Aph., 4, 370.

Chamberlain, J. W . 1961, Physics of the Aurora and Airglow, Academic Press.

Chamberlain, J. W. and Smith 1959, J. G. R. 64, 611.

Dunn, R. B. and Manring, E. R. 1955, Jnl. Opt. Soc. Amer. 45, 899.

Elsässer, H. 1963, Planet. Space Sci., 11, 1015.

Elsässer, H. and Haug, U. 1960, Zs. F. Aph., 50, 121.

Elvey, C. T. and Roach, F. E. 1937, Ap. J. 85, 231.

Gillett, F. C., Huch, W. F., and Ney, E. P. 1964 in press (J.G.R.)

Henyey, L. G. and Greenstein, J. L. 1941, Ap. J. 93, 70.

Houten, C. J. van 1961, B. A. N. 16, 1.

Hulst, H. C. van de 1957, Light Scattering By Small Particles (Wiley).

Hulst, H. C. van de 1947, Ap. J. 105, 471.

Hunten, D. M., Roach, F. E. and Chamberlain, J. W. 1956, J. Atm. Terr. Phys., 8, 345.

Ingham, M. F. 1961, M. N. R. A. S., 122, 157.

Koomen, M. J., Gulledge, I. S., Packer, D. M., and Tousey, R. 1963, Science, 140, 1087.

Krassofsky, V. I., Shefov, N. N., and Yarin, V. I. 1962, Planetary and Space Science 9, 883.

Rhijn, P. J. van 1921, Publ. Ast. Lab. Groningen Number 31, pp 1-83.

Rhijn, P. J. van 1925, Publ. Ast. Lab. Groningen Number 43.

Roach, F. E. 1963, "The Nightglow" in Advances in Electronics, 18, 1.

Roach, F. E. and Megill, L. R. 1961, Ap. J. 133, 228.

Roach, F. E., Megill, L. R., Rees, M. H., and Marovich E. 1958, J. A. T. P. 12, 171.

Roach, F. E. and Meinel, A. B. 1955, Ap. J. 122, 530.

Roach, F. E., Pettit, H. B., Tanoberg-Hannsen, E., and Davis, D. N. 1954, Ap. J., 119, 253.

Roach, F. E. and Rees, M. H. 1955 in "The Airglow and The Aurorae", Pergamon Press, page 142.

Roach, F. E. and Smith, L. L. 1964a, NBS Technical Note Number 214.

Roach, F. E. and Smith, L. L. 1964b, Unpublished Material.

Seares, F. H., Rhijn, P. J. van, Joyner, M. C. and Richmond, M. L. 1925, Ap. J. 62, 320; Mt. Wilson Contribution number 301.

Trumpler, R. J. and Weaver, H. F., Statistical Astronomy, Dover Publications 1962; originally published by the University of California Press (1953).

Wang Shih-Ky 1937, Publications de l'Observatoire de Lyon, fasc 19, Vol. 1.

Weinberg, J. L. 1963, Ph. D. Dissertation, University of Colorado.

Yntema, L. 1909, Publ. Ast. Lab. Groningen, No. 22, pp 1-55.

Table 1

Approximate intensity of visual radiation at various locations in the universe.
In S_{10} (vis) units.

Observer / Component	In intergalactic space	In interstellar space	In interplanetary space	On the earth
Integrated nebular light	1	1	1	1
Integrated starlight	-	100	100	100
Zodiacal light	-	-	200	200
Night airglow	-	-	-	150
Total	1	101	301	451

Table 2

The Galaxy (The Kapteyn Universe)

Total Number of Stars	47,000,000,000
Density of stars	
Central	45/cubic parsec
Thickness	
To 1/10 density	550 parsecs
To 1/100 density	1700 "
Diameter	
To 1/10 density	2800 parsecs
To 1/100 density	8500 "
Distance of the sun	
From the center	8000 parsecs

Table 3

Summary of Star Counts by magnitude intervals
from M W 301

m (pg)	log A(m) b=0	log A(m) b=90	log A(m) Mean(b=0 to 90)	log T(m) b=0 to 90 (over entire sphere)
4	-1.781	-2.320	-2.035	2.580
5	-1.326	-1.861	-1.580	3.035
6	-0.875	-1.416	-1.130	3.485
7	-0.428	-0.984	-0.688	3.927
8	+0.016	-0.567	-0.252	4.364
9	+0.455	-0.170	+0.175	4.790
10	0.889	+0.209	0.591	5.206
11	1.314	0.565	0.995	5.610
12	1.733	0.898	1.338	6.003
13	2.141	1.205	1.767	6.382
14	2.532	1.491	2.127	6.742
15	2.902	1.752	2.471	7.086
16	3.248	1.988	2.795	7.410
17	3.571	2.194	3.095	7.710
18	3.874	2.374	3.373	7.988
19	4.153	2.531	3.626	8.241
20	4.405	2.654	3.857	8.472
21	4.631	2.743	4.067	8.682

Table 4

Integrated Starlight from Star Counts

	J (pg)			J (vis)
b	MW 301	GR 43	Difference	GR 43
0	103	172	69	372
5	93	116	23	246
10	77	84	7	175
15	61	66	5	136
20	48	51	3	103
30	34	35	1	69
40	26	27	1	52
50		22		41
60	18	19	1	36
70		17		32
80		16		31
90	14			

Table 5

Summary of Cosmic Dust

Source	$\beta = \pi a^2 N$ (cm^{-1})	Estimated distance or extent, R (cm)	βR	$e^{-\beta R}$	$1-e^{-\beta R}$	R(0.01) (cm)
Tropospheric Dust	2.25×10^{-7}	3×10^{5} (3km)	6.75×10^{-2}	0.94	0.06	2×10^{7} (200km)
Local Dust in upper Atmosphere	1.5×10^{-17} to 1.5×10^{-16}	10^{7} (100km) to 10^{6} (10km)	10^{-10}	$1-10^{-10}$	10^{-10}	3×10^{17} (1/10pc) to 3×10^{16} (1/100pc)
Zodiacal Cloud	1.5×10^{-19}	1.5×10^{13} (1A.U.)	2.25×10^{-6}	$1-(2.25\times10^{-6})$	2.25×10^{-6}	3×10^{19} (10pc)
Galactic Dust	1×10^{-22}	6.2×10^{21} (2kpc) 6.2×10^{22} (20kpc)	0.62 6.2	0.54 0.002	0.46 0.998	4.6×10^{22} (15kpc)

Conversions:

1 Astronomical Unit (A.U.) = 1.496×10^{13} cm; $\log_{10}$ = 13.17

1 Parsec (pc) = 206,265 A.U. = 3.09×10^{18} cm; $\log_{10}$ = 18.49

3.26 Light years (L.Y.) = 1 Parsec (pc)

1 Kiloparsec (kpc) = 3.09×10^{21} cm; $\log_{10}$ = 21.49

Table 6

Relative Intensity V_z' of the Sky as a Function of Zenith Distance.

Haleakala. Four nights (1961–1962). Filter centered at 5300 A.

Zenith Distance	V_z'			% upper atmosphere (deduced)
z	Observed	Predicted		
		100% upper atmosphere (h=100 km)	100% astronomical	
0	1.000	1.000	1.000	–
40	1.145	1.263	0.985	–
60	1.230	1.772	0.953	–
70	1.341	2.265	0.921	31
75	1.407	2.586	0.885	30
80	1.439	2.865	0.842	30

Table 7

Nightglow Emissions (largely from Krassovsky, Shefov and Yarin, 1962)

Source	Wavelength	Absolute zenith intensity: Rayleighs	Absolute zenith intensity: $Ergs \cdot cm^{-2} (column) \cdot sec^{-1}$
OH	0.38 to 4.5	5,000,000	3.6
O_2(0, 1 atm)	8645 A	500	1.1×10^{-3}
HI ($H\alpha$)	6563 A	15	4.5×10^{-5}
OI	6300, 6364 A	200	6.2×10^{-4}
NaI	5890, 5896 A	30 (summer) to 200 (winter)	1.0×10^{-4} to 6.8×10^{-4}
OI	5577 A	250	8.9×10^{-4}
HI ($H\beta$)	4861 A	3	1.2×10^{-5}
O_2 (Herzberg Bands)	3000 to 4000 A	1500	8.8×10^{-3}
N_2^+	3914	(40)*	2.0×10^{-5}
Continuum (Nightglow)	4000-7000 A	900 (0.3 R/A Mean)	5.0×10^{-3}
Continuum (Astronomical		4000 (1.3 R/A Mean)	1.5×10^{-2}

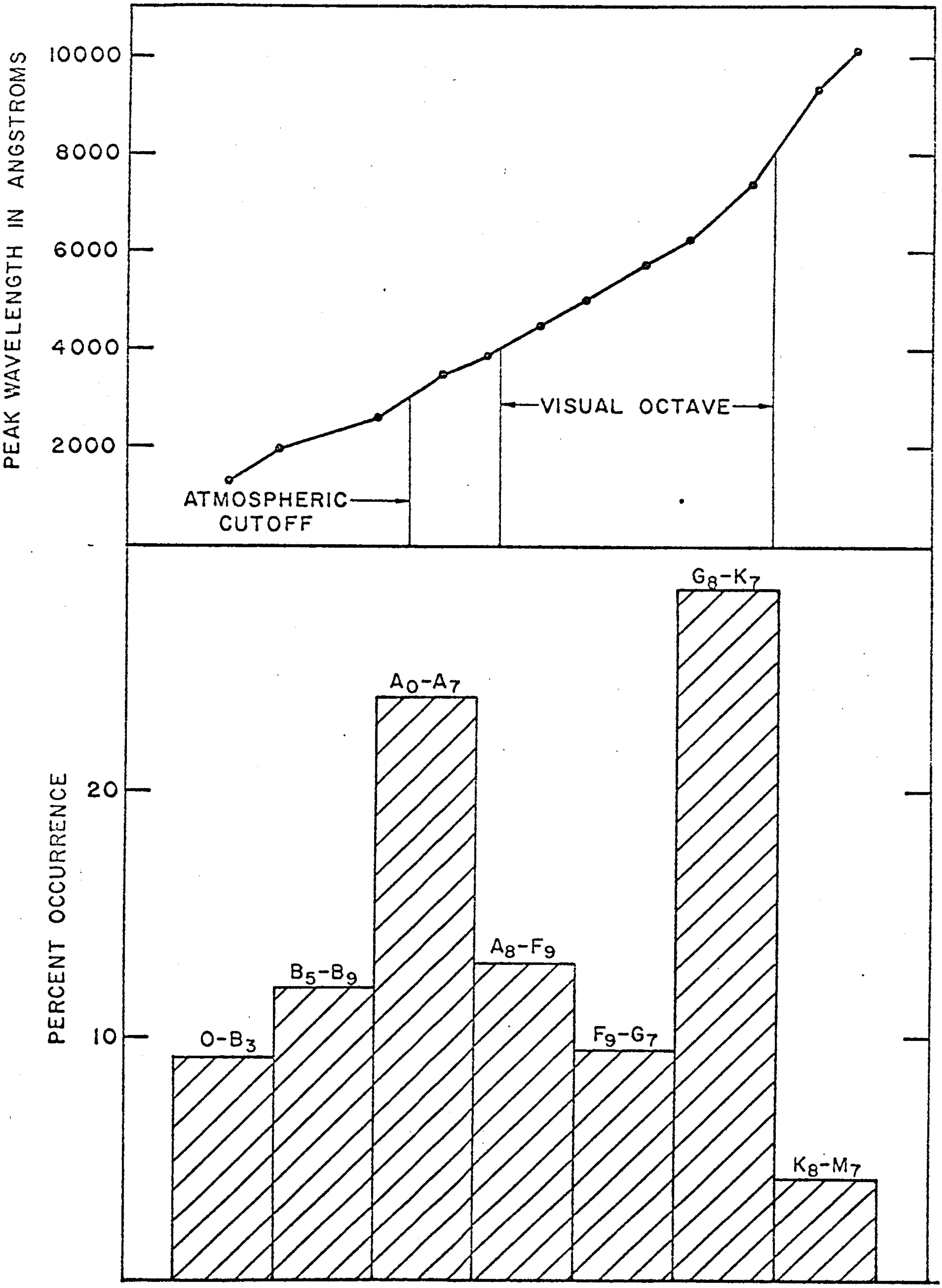
* The presence of N_2^+ 3914 A as a "nightglow" emission is uncertain. It is a prominent feature of the aurora.

Note: In table 7 and 8 the "rayleigh" unit of airglow intensity is used. It may be defined as follows: "If the surface brightness, B, is measured in units of 10^6 quanta. cm^{-2}. sec^{-1}. $steradian^{-1}$ then the intensity in rayleighs is $4\pi B$" (See Hunten, Roach and Chamberlain (1956)).
In the case of a continuum the specific intensity in rayleighs per Angstrom (R/A) is useful. At a wavelength of 5300A 1 R/A = 227 S_{10} (vis).

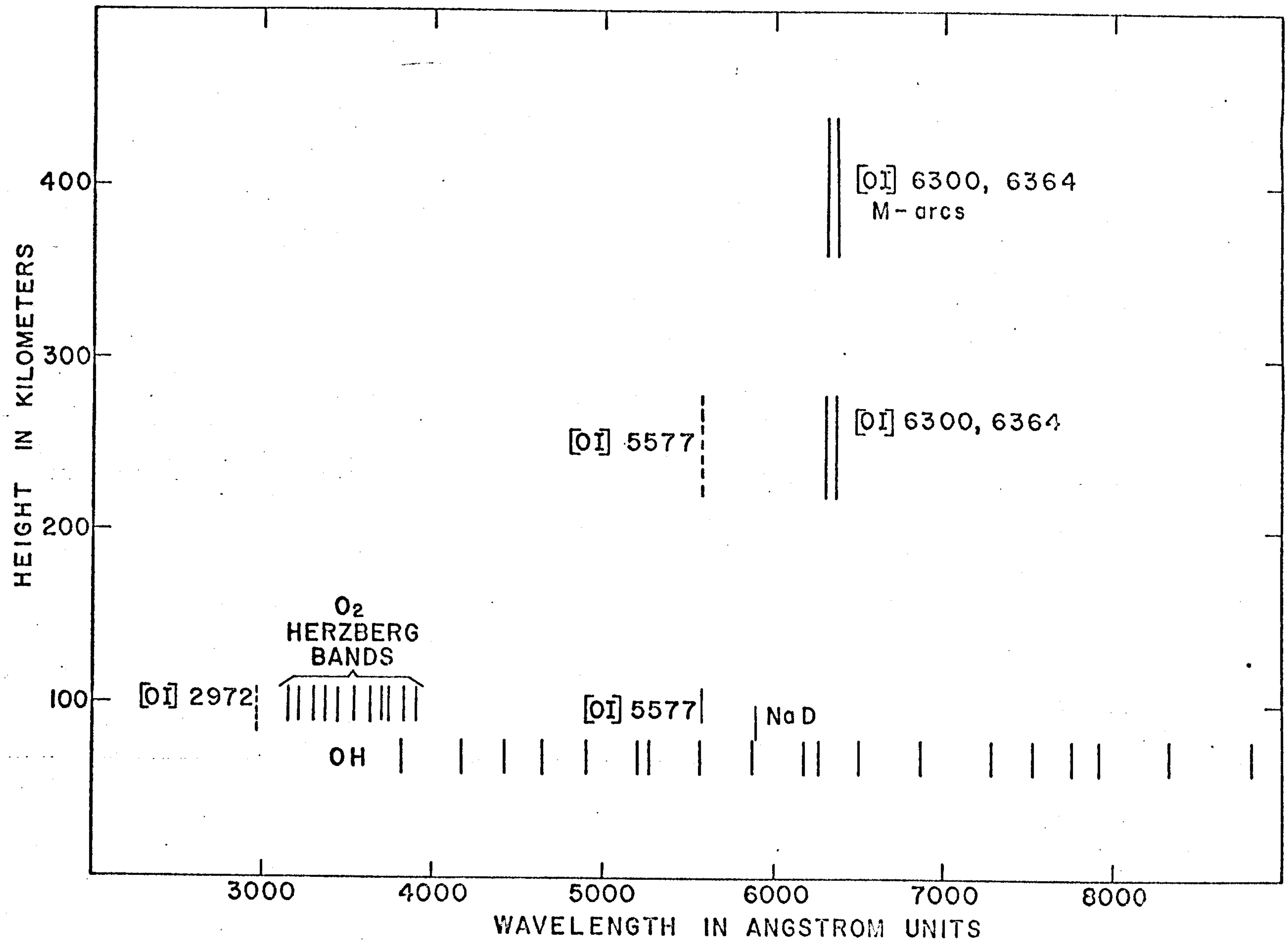
Table 8

List of OH Bands in Order of Wavelength

Wave-length air (A)	Transition (v' - v")	Absolute intensity in rayleighs (Chamberlain and Smith, 1959)	Wave-length air (A)	Transition (v' - v")	Absolute intensity in rayleighs (Chamberlain and Smith, 1959)
3,816.6	9-0	0.023	10,828	5-2	12,000
4,172.9	8-0	0.12	11,433	6-3	15,000
4,418.8	9-1	0.73	12,115	7-4	17,000
4,640.6	7-0	0.71	12,898	8-5	16,000
4,903.5	8-1	3.8	13,817	9-6	13,000
5,201.4	9-2	11.0	14,336	2-0	46,000
5,273.3	6-0	4.4	15,047	3-1	74,000
5,562.2	7-1	22	15,824	4-2	88,000
5,886.3	8-2	57	16,682	5-3	90,000
6,168.6	5-0	33	17,642	6-4	82,000
6,256.0	9-3	110	18,734	7-5	71,000
6,496.5	6-1	130	19,997	8-6	54,000
6,861.7	7-2	310	21,496	9-7	37,000
7,274.5	8-3	520	28,007	1-0	920,000
7,521.5	4-0	280	29,369	2-1	820,000
7,748.3	9-4	710	30,854	3-2	640,000
7,911.0	5-1	930	32,483	4-3	490,000
8,341.7	6-2	1800	34,294	5-4	360,000
8,824.1	7-3	2800	36,334	6-5	260,000
9,373.0	8-4	3400	38,674	7-6	180,000
9,788.0	3-0	3100	41,409	8-7	110,000
10,010	9-5	3600	44,702	9-8	65,000
10,273	4-1	7600			


PEAK WAVELENGTH IN ANGSTROMS
10000
8000
6000
4000
2000
ATMOSPHERIC CUTOFF
VISUAL OCTAVE
PERCENT OCCURRENCE
20
10
O-B_3
B_5-B_9
A_0-A_7
A_8-F_9
F_9-G_7
G_8-K_7
K_8-M_7

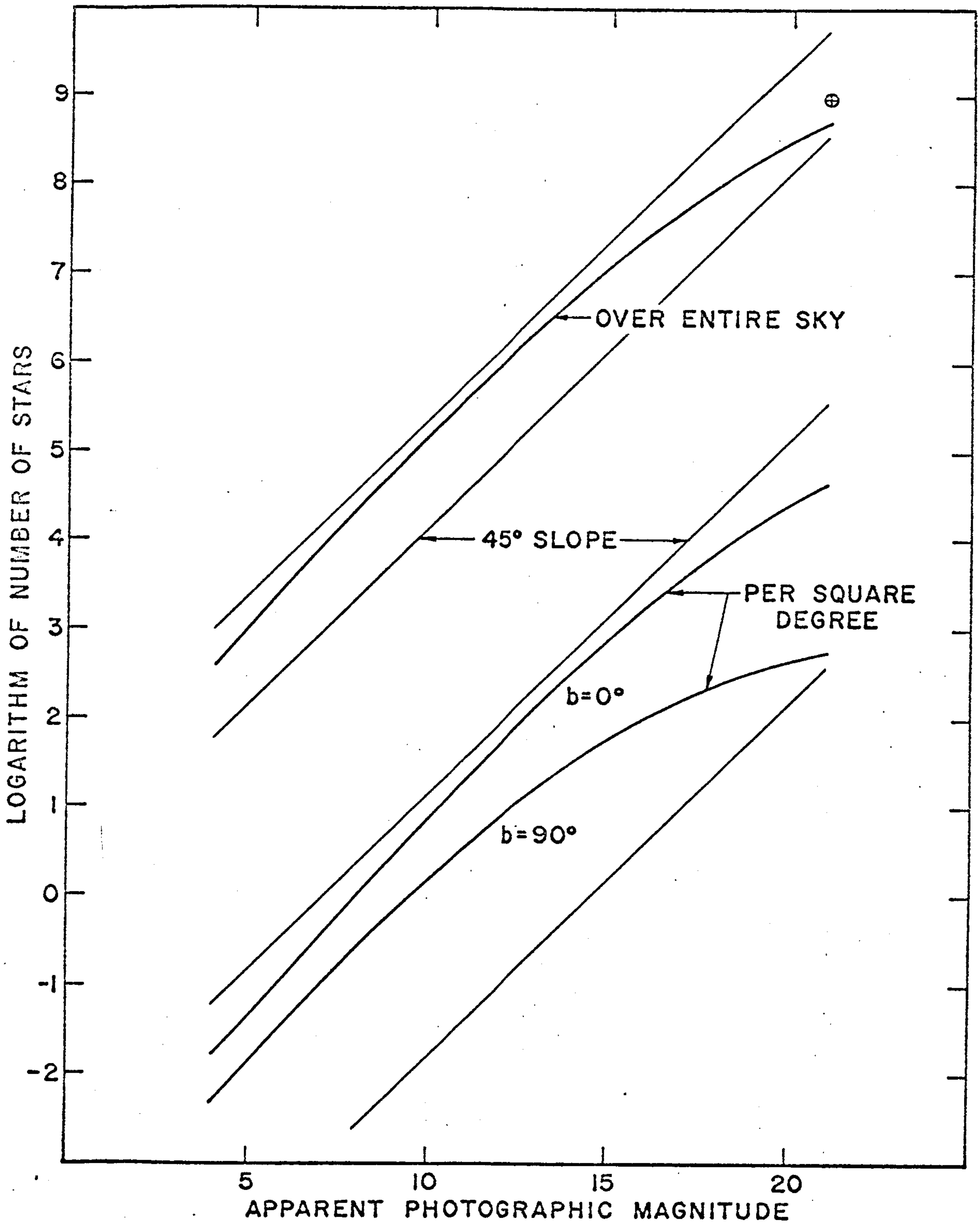
(1)



HEIGHT IN KILOMETERS
400
300
200
100
[OI] 6300, 6364
M-arcs
[OI] 5577
[OI] 6300, 6364
O_2
HERZBERG
BANDS
[OI] 2972
[OI] 5577
Na D
OH
3000
4000
5000
6000
7000
8000
WAVELENGTH IN ANGSTROM UNITS

(2)

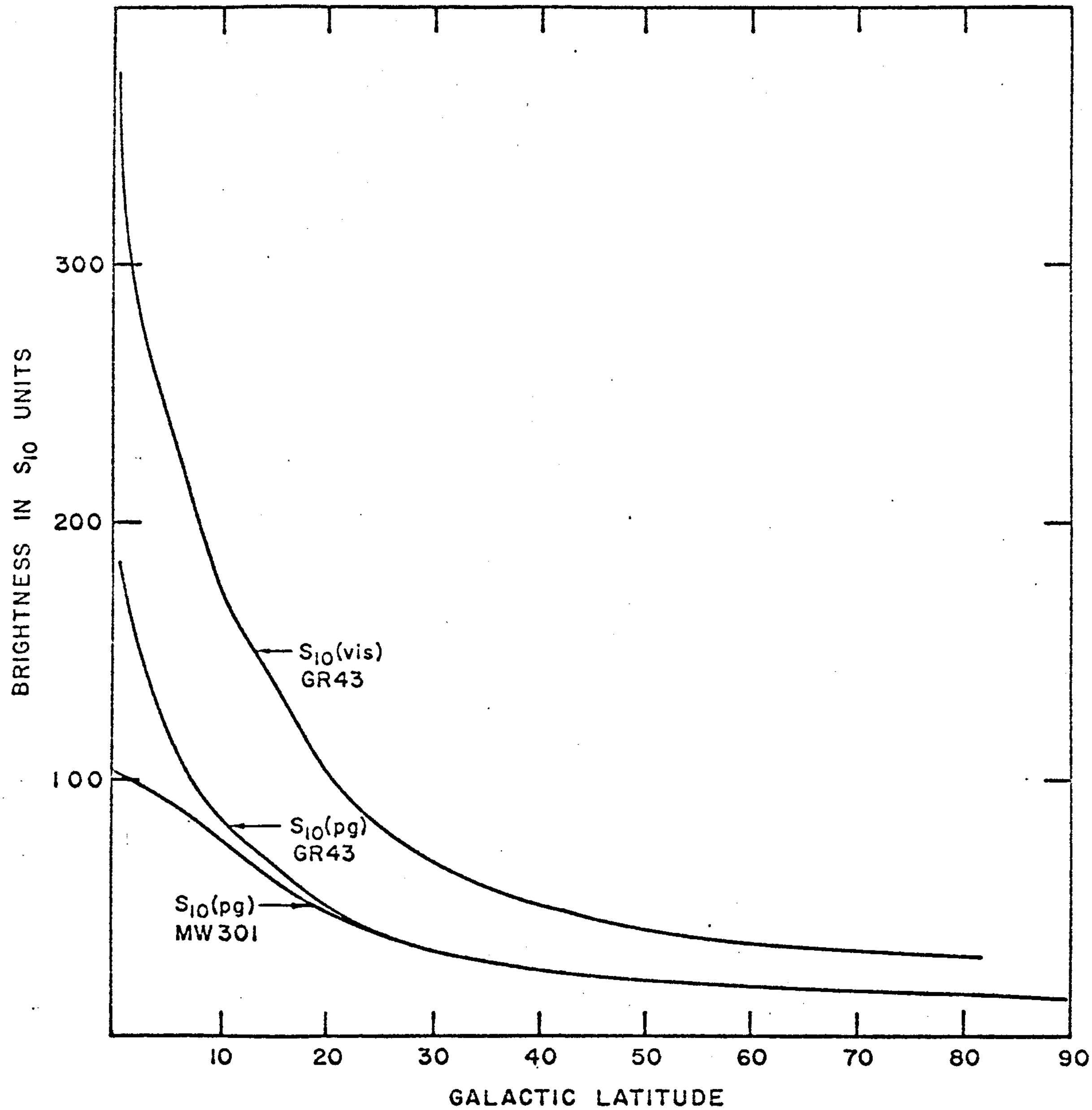
B-45546



LOGARITHM OF NUMBER OF STARS
9
8
7
6
5
4
3
2
1
0
-1
-2
⊕
OVER ENTIRE SKY
45° SLOPE
PER SQUARE DEGREE
b=0°
b=90°
5
10
15
20
APPARENT PHOTOGRAPHIC MAGNITUDE

3

B-45543


BRIGHTNESS IN S_{10} UNITS
300
200
100
S_{10}(vis)
GR43
S_{10}(pg)
GR43
S_{10}(pg)
MW301
10
20
30
40
50
60
70
80
90
GALACTIC LATITUDE

4

B-45542

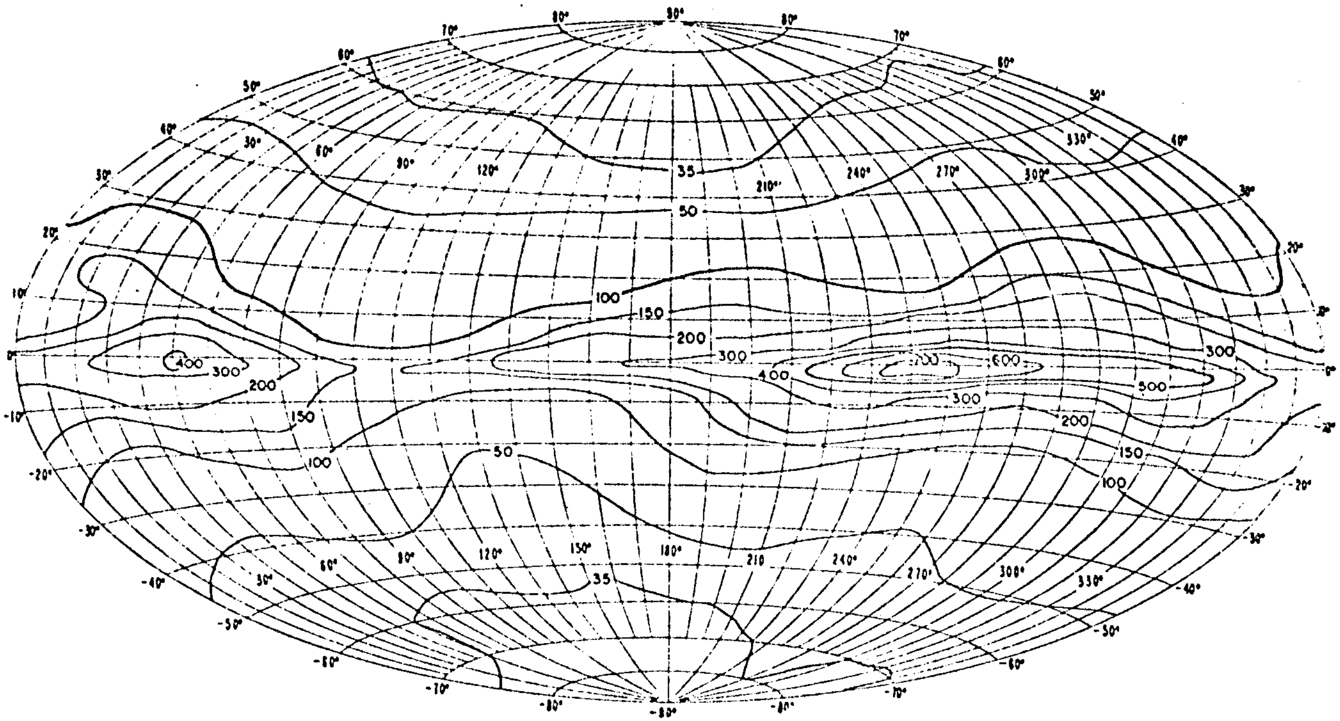
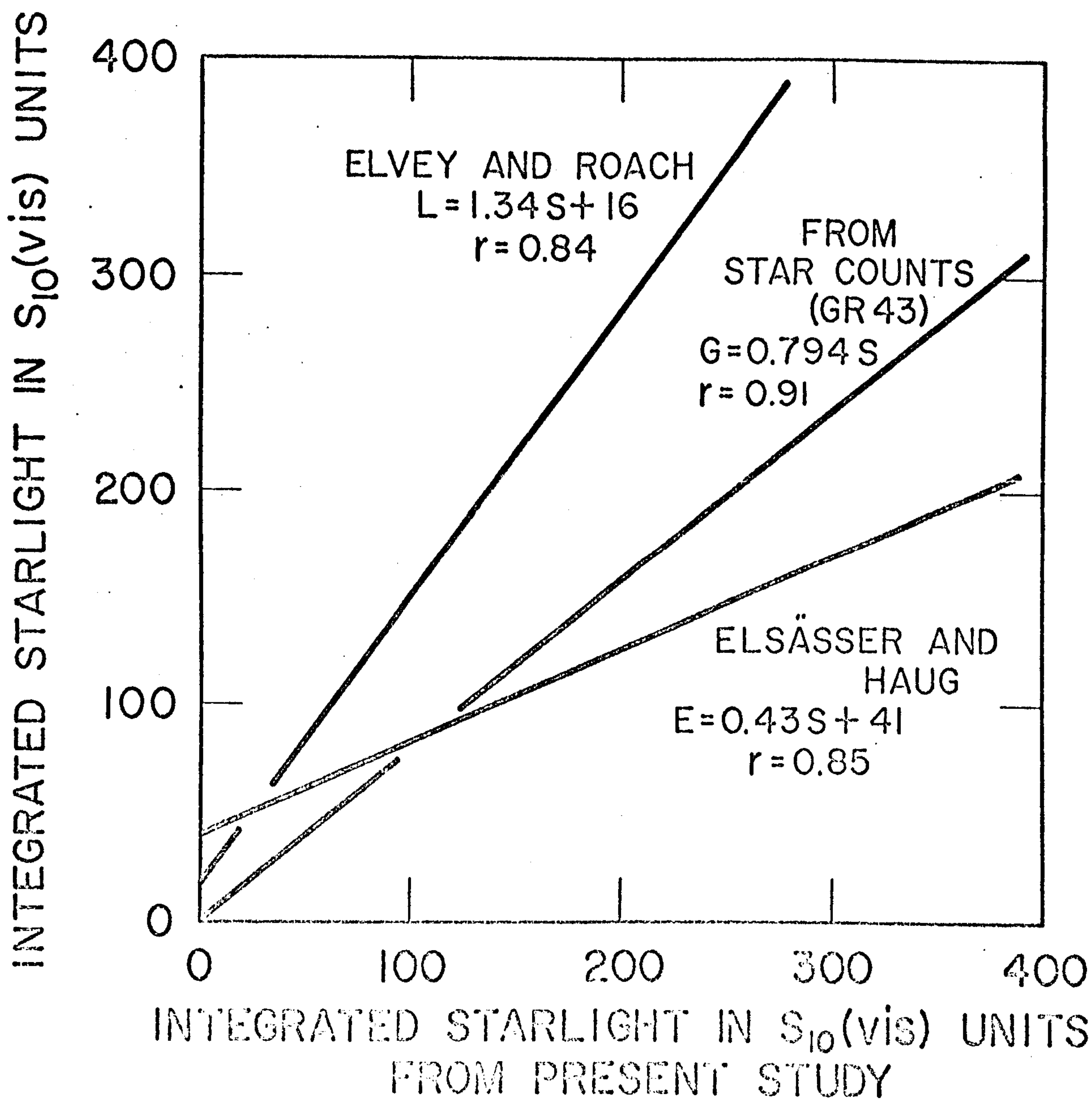


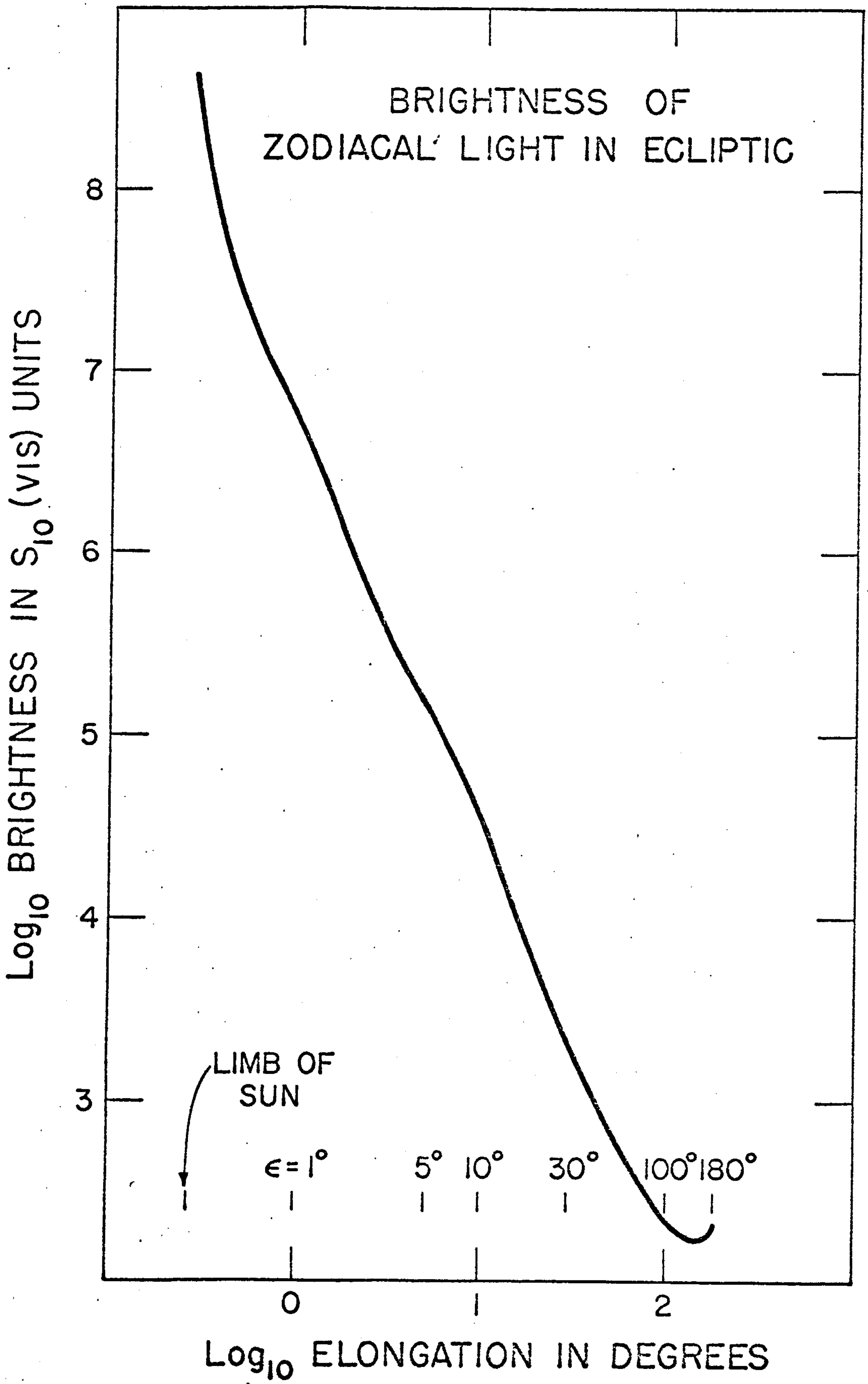
Fig. 5—Total integrated starlight in number of tenth-magnitude (visual) stars per square degree in galactic co-ordinates

[B- 45893]


ELVEY AND ROACH
L = 1.34 S + 16
r = 0.84
FROM
STAR COUNTS
(GR 43)
G = 0.794 S
r = 0.91
ELSÄSSER AND
HAUG
E = 0.43 S + 41
r = 0.85
INTEGRATED STARLIGHT IN S_{10}(vis) UNITS
INTEGRATED STARLIGHT IN S_{10}(vis) UNITS
FROM PRESENT STUDY
0
100
200
300
400

B- 44301

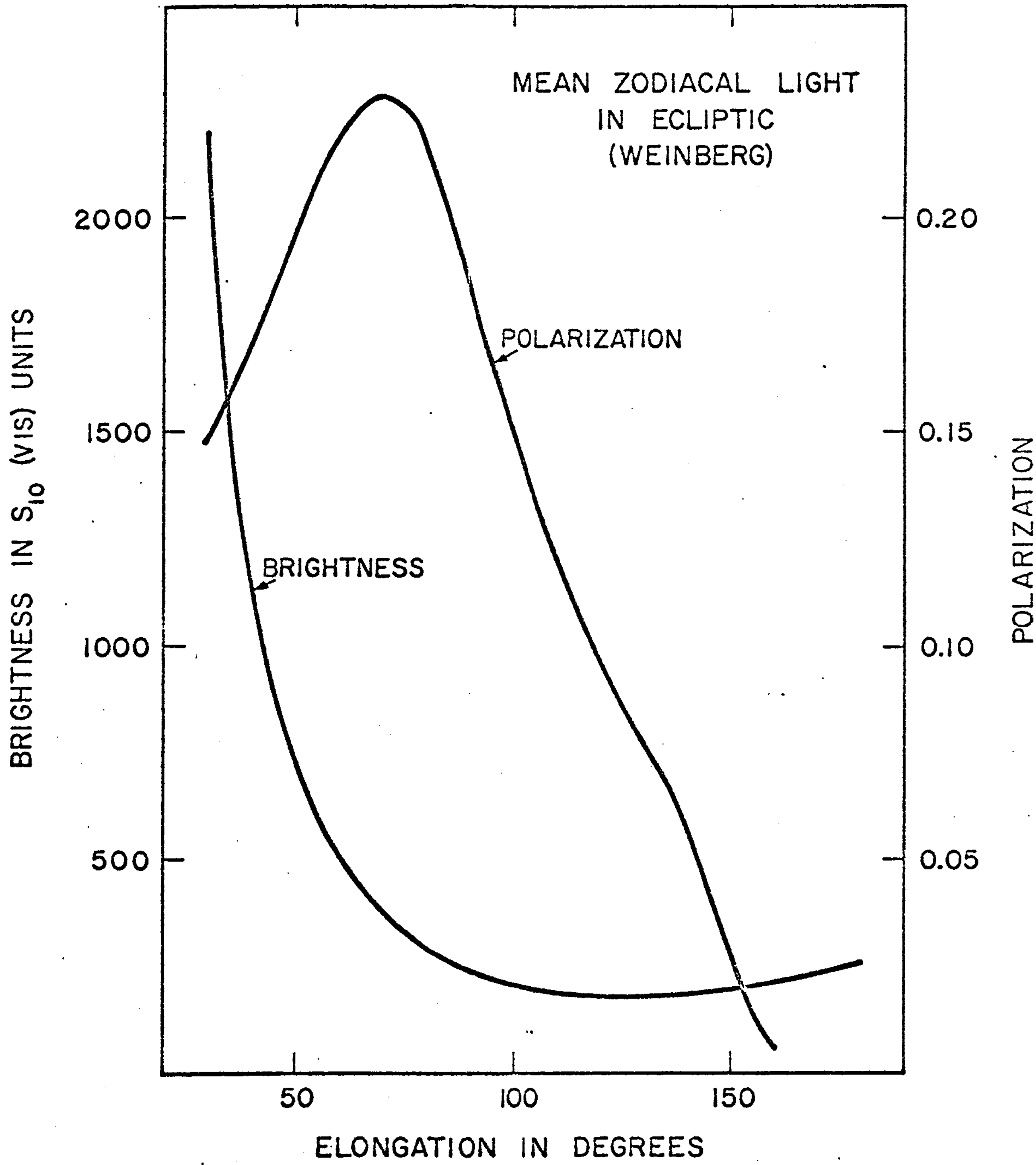
Fig 8



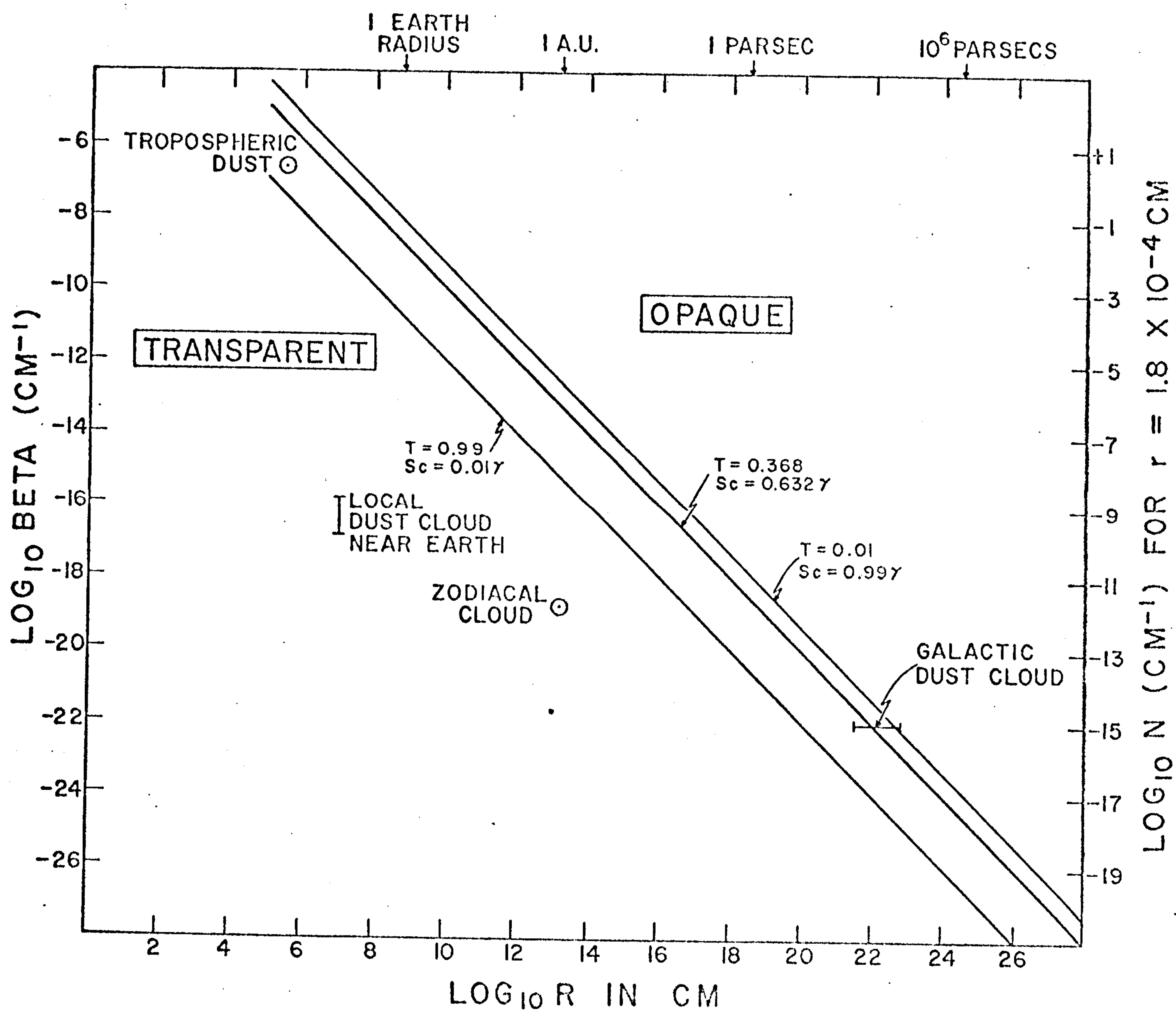
BRIGHTNESS OF
ZODIACAL LIGHT IN ECLIPTIC
Log10 BRIGHTNESS IN S10 (VIS) UNITS
8
7
6
5
4
3
LIMB OF
SUN
ε = 1°
5°
10°
30°
100°
180°
0
1
2
Log10 ELONGATION IN DEGREES

B-45919

Fig 7


MEAN ZODIACAL LIGHT
IN ECLIPTIC
(WEINBERG)
POLARIZATION
BRIGHTNESS
2000
1500
1000
500
0.20
0.15
0.10
0.05
50
100
150
BRIGHTNESS IN S_{10} (VIS) UNITS
POLARIZATION
ELONGATION IN DEGREES

B-45917

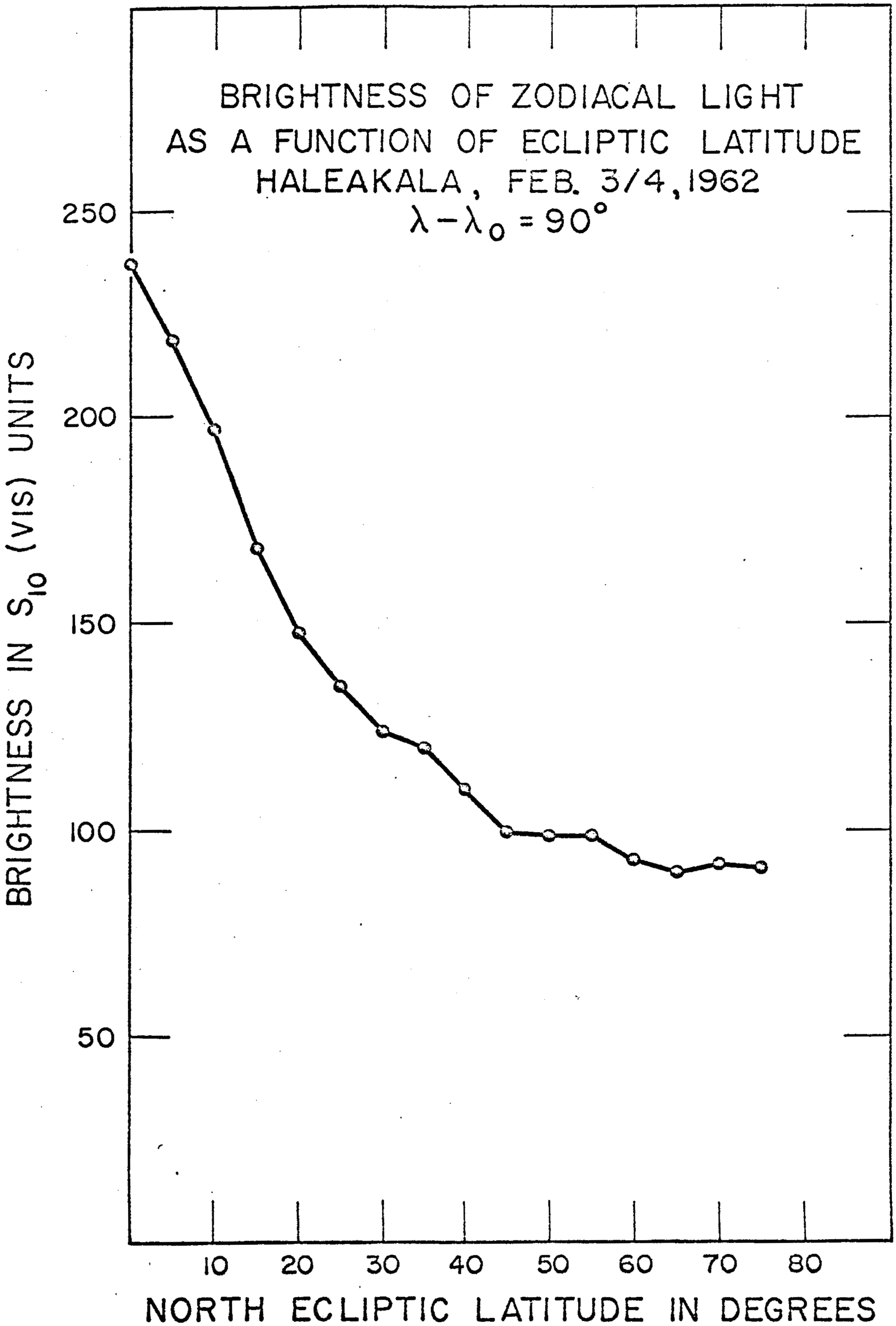


1 EARTH RADIUS
1 A.U.
1 PARSEC
10^6 PARSECS
TROPOSPHERIC DUST
TRANSPARENT
OPAQUE
T = 0.99
Sc = 0.01γ
T = 0.368
Sc = 0.632γ
T = 0.01
Sc = 0.99γ
LOCAL DUST CLOUD NEAR EARTH
ZODIACAL CLOUD
GALACTIC DUST CLOUD
LOG_{10} BETA (CM^{-1})
LOG_{10} N (CM^{-1}) FOR r = 1.8 X 10^{-4} CM
LOG_{10} R IN CM

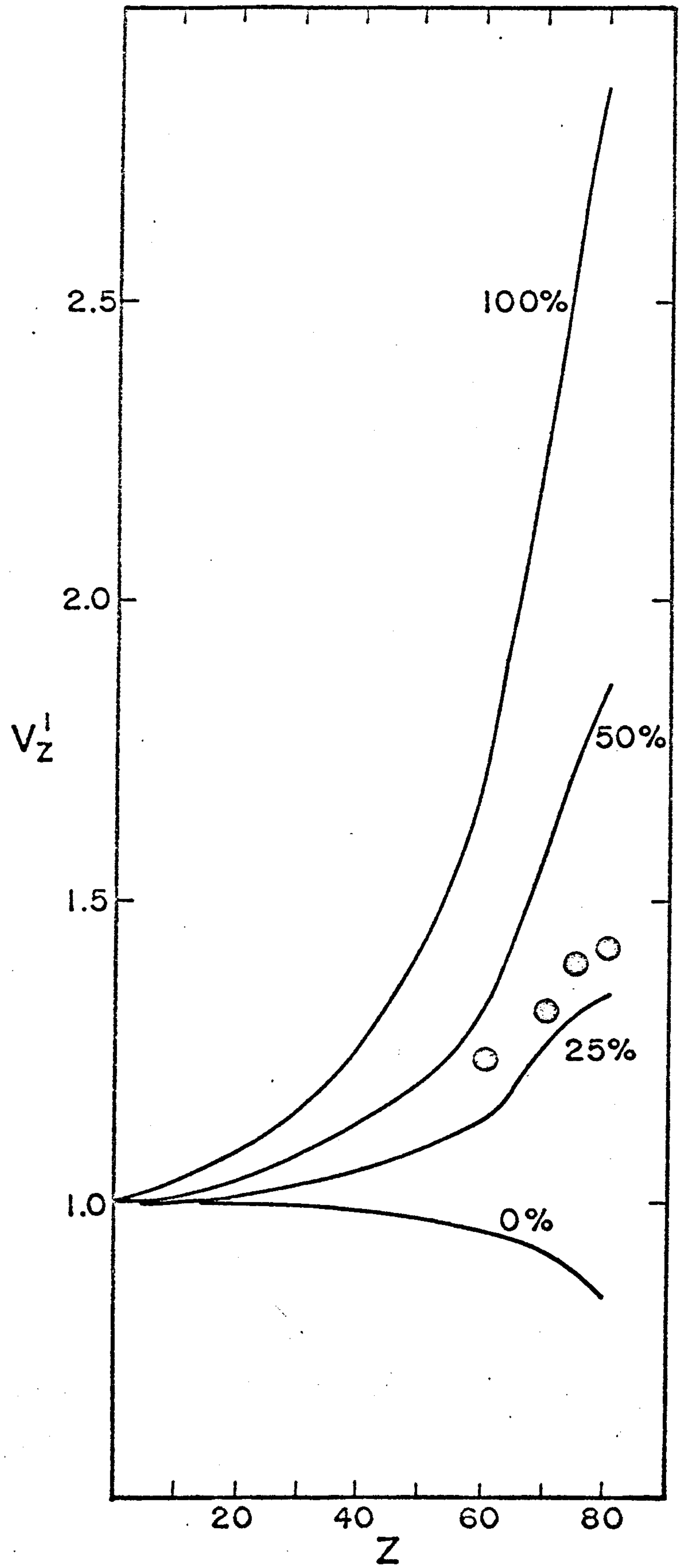
10

B-45544

Fig 9


BRIGHTNESS OF ZODIACAL LIGHT
AS A FUNCTION OF ECLIPTIC LATITUDE
HALEAKALA, FEB. 3/4, 1962
$\lambda - \lambda_0 = 90°$
BRIGHTNESS IN S_{10} (VIS) UNITS
250
200
150
100
50
10
20
30
40
50
60
70
80
NORTH ECLIPTIC LATITUDE IN DEGREES

B-43918



11

B-45539

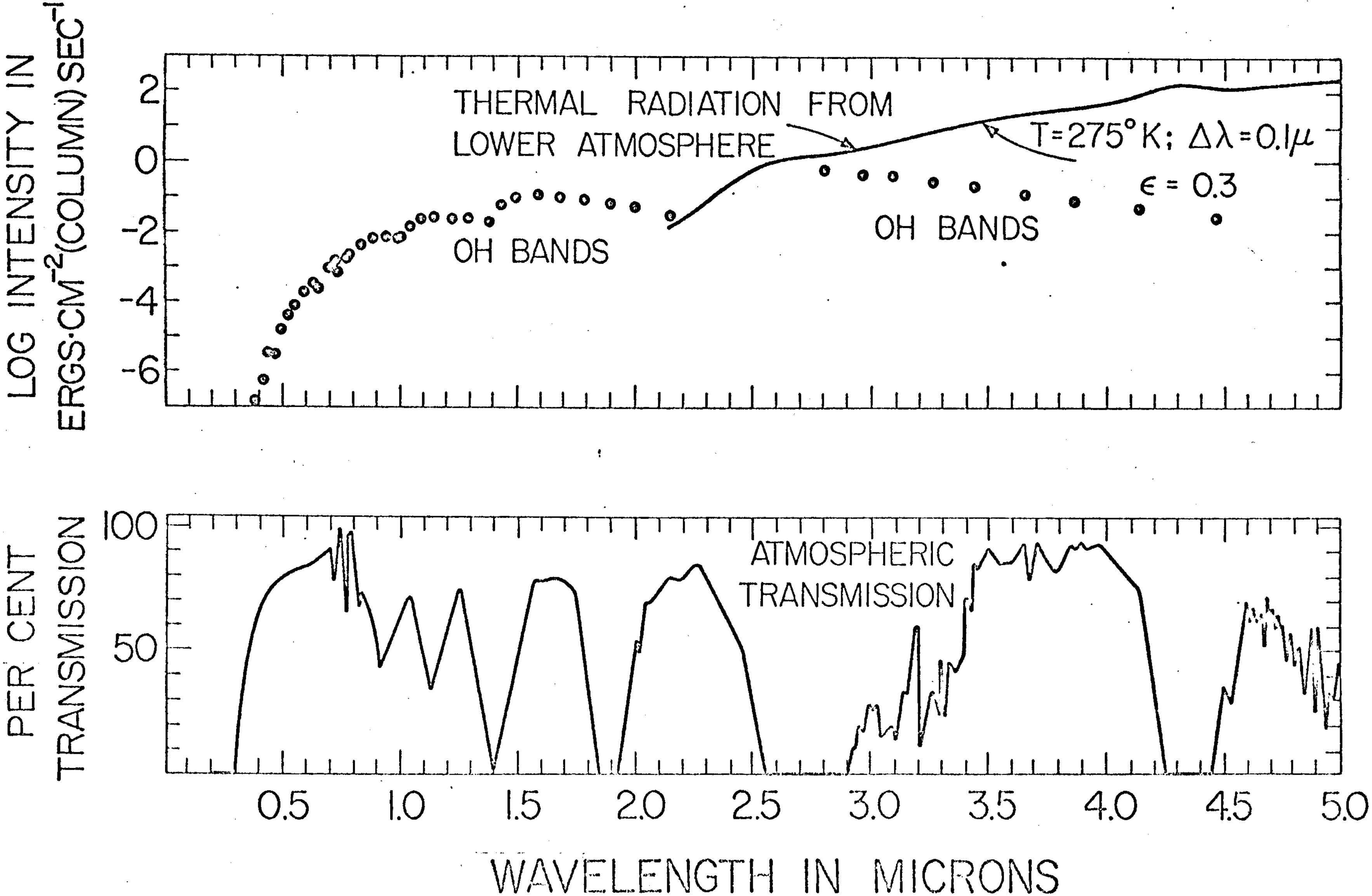
Figure 12

Photograph

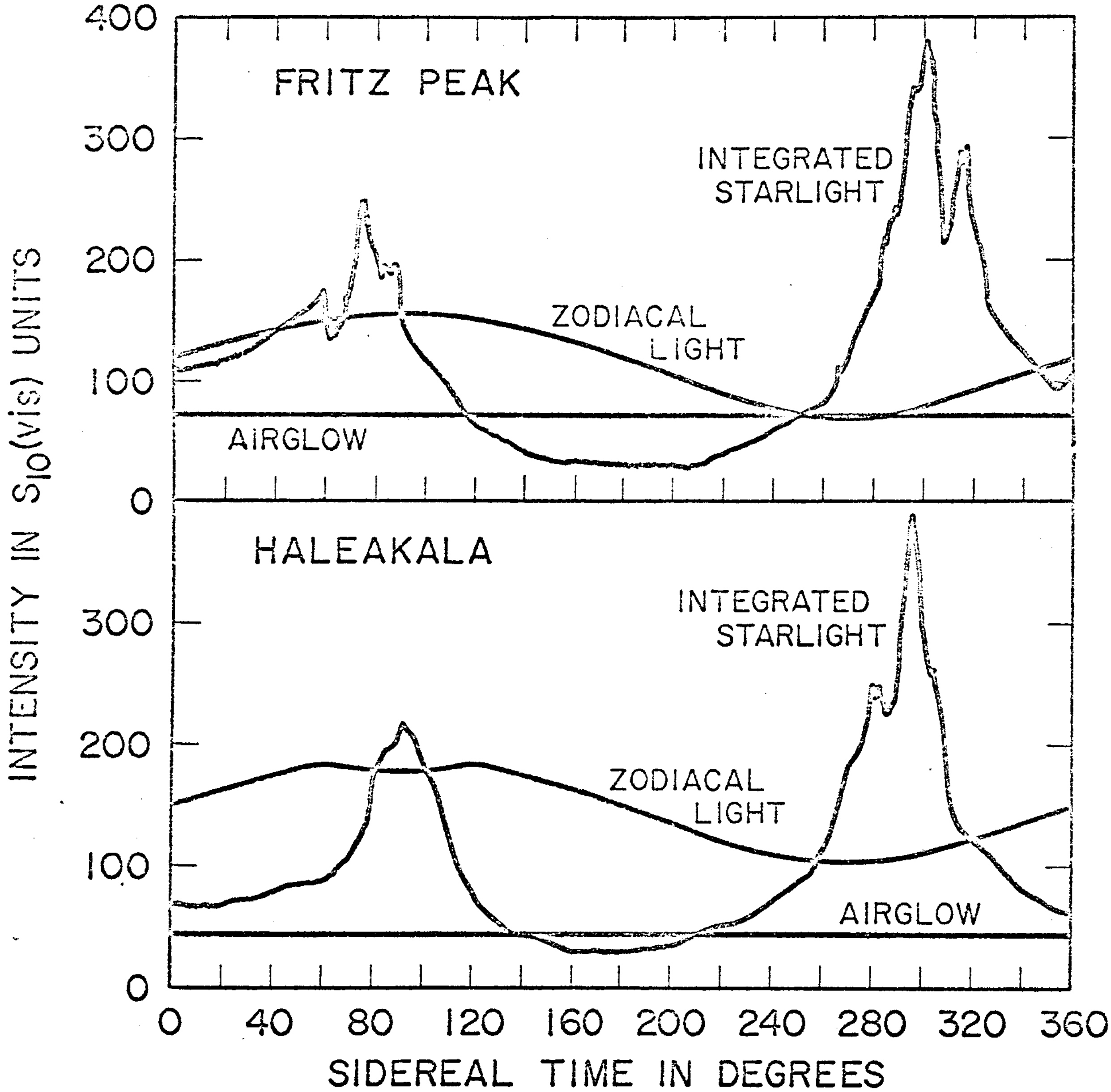
by Cooper

Sent to de Jager.

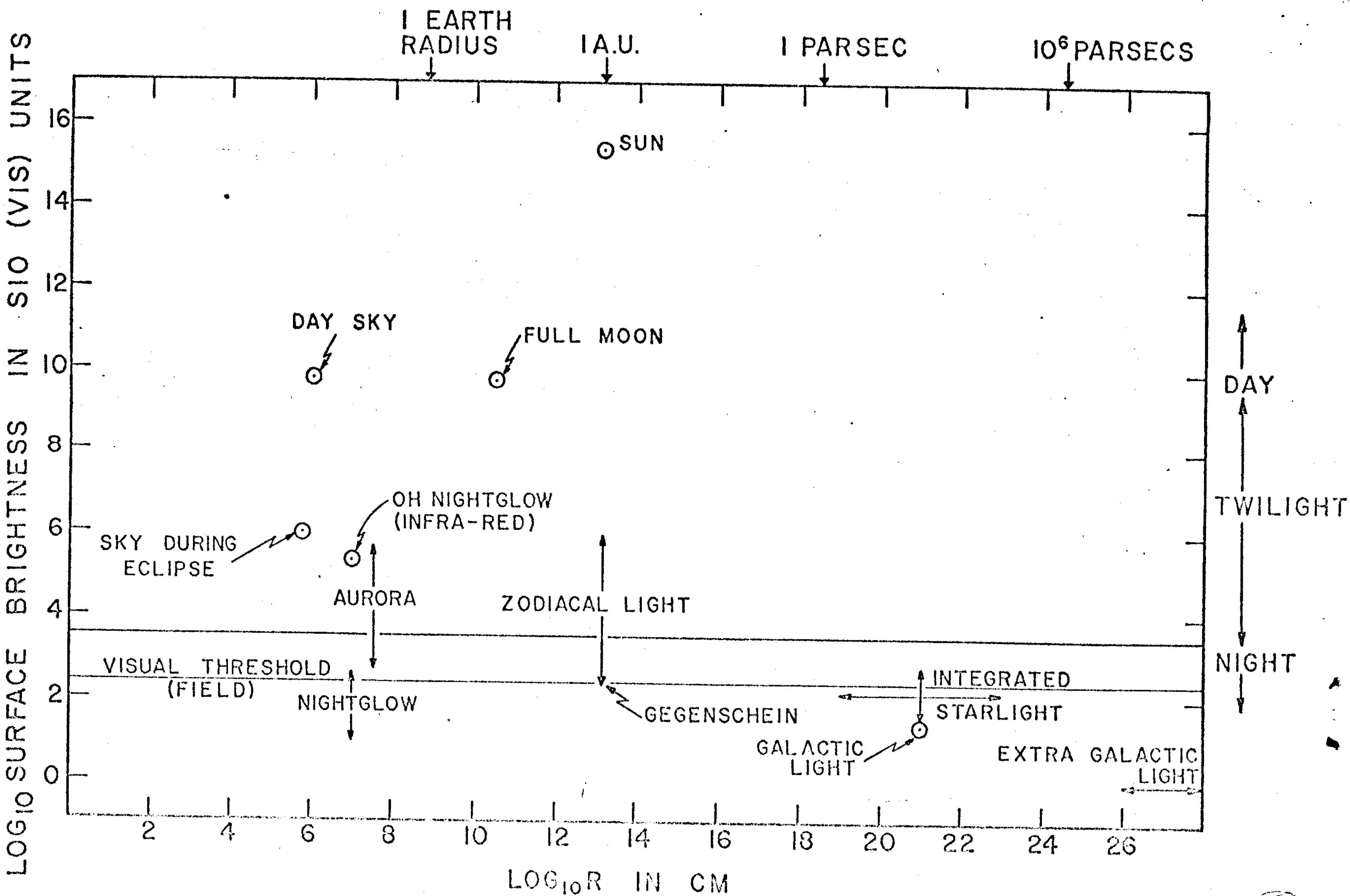
This is from a paper by Gillett, Hecht & King to be published in JGR. (July, 1964)


LOG INTENSITY IN ERGS·CM⁻²(COLUMN) SEC⁻¹
THERMAL RADIATION FROM LOWER ATMOSPHERE
T=275° K; Δλ=0.1μ
ε = 0.3
OH BANDS
OH BANDS
PER CENT TRANSMISSION
ATMOSPHERIC TRANSMISSION
WAVELENGTH IN MICRONS
2
0
-2
-4
-6
100
50
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

B-36225


FRITZ PEAK
INTEGRATED STARLIGHT
ZODIACAL LIGHT
AIRGLOW
HALEAKALA
INTEGRATED STARLIGHT
ZODIACAL LIGHT
AIRGLOW
400
300
200
100
0
300
200
100
0
INTENSITY IN S_{10}(vis) UNITS
0
40
80
120
160
200
240
280
320
360
SIDEREAL TIME IN DEGREES

B-44246



I EARTH RADIUS
I A.U.
I PARSEC
10^6 PARSECS
SUN
DAY SKY
FULL MOON
OH NIGHTGLOW (INFRA-RED)
SKY DURING ECLIPSE
AURORA
ZODIACAL LIGHT
VISUAL THRESHOLD (FIELD)
NIGHTGLOW
GEGENSCHEIN
INTEGRATED STARLIGHT
GALACTIC LIGHT
EXTRA GALACTIC LIGHT
DAY
TWILIGHT
NIGHT
LOG10 SURFACE BRIGHTNESS IN SIO (VIS) UNITS
LOG10R IN CM

15